Volume XXXIII August 1938 Number 5

Economic Geology

and the

Bulletin of the Society of Economic Geologists

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ECONOMIC GEOLOGY

VOL. XXXIII AUGUST, 1938 No. 5

THE ORIGIN OF THE IRON ORE DEPOSITS IN THE BULL VALLEY AND IRON SPRINGS DISTRICTS, UTAH.[1]

FRANCIS G. WELLS.

ABSTRACT.

A summary of the geology of the Bull Valley district, southwestern Utah, and a description of the occurrence of the magnetite and hematite deposits is given, as well as brief descriptions of the ore pits at Iron Mountain and Desert Mound 20 miles to the northeast, in which deposits formed under similar geologic conditions have been developed. Neither the ores nor the country rock show the features characteristic of contact-metamorphic deposits. The following explanation of the origin of the deposits is offered. During the intrusion of monzonite porphyry stocks, the hoods and overlying rock were fractured, causing a sudden release of pressure and liberating $FeCl_2$ and H_2O gas from the stocks which were still at high temperature. These gases found ready egress to the surface along tension fissures without appreciably heating the country rock. They deposited magnetite and hematite in the fissures and replaced the contiguous fractured limestone. The period of gas emanation was brief and the hydrothermal stage probably evolved during the later magmatic history never reached this area. The deposits were formed under a cover of less than 5,000 feet.

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[1] Published by permission of the Director of the United States Geological Survey. Presented before the Society of Economic Geologists, New York Meeting, February, 1937.

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INTRODUCTION.

It has long been reported that large deposits of iron ore existed at Bull Valley in the rugged mountainous area 20 miles southwest of the Iron Springs district, and 40 miles southwest of Cedar City in southwestern Utah, and, because of the interest in ore deposits tributary to Boulder Dam, the Bull Valley deposits were studied in the summer of 1935, as a project of the Federal Geological Survey. In the Iron Springs district, the outstanding source of iron ore in the region west of the Rocky Mountains, two and one-half million tons of ore have been produced from the beginning of operation in 1923 to January 1, 1937.

The Iron Springs district was described by C. K. Leith and E. C. Harder.[2]

The facts about this district used in this paper are derived in part from their Bulletin, in part from observations made by the writer during two brief visits to the pits at Iron Mountain and Desert Mound, and in part from data supplied by the operating companies.

[2] Leith, C. K., and Harder, E. C.: The iron ores of the Iron Springs district, Utah. U. S. Geol. Surv. Bull. 338, 102 pp., 1908.

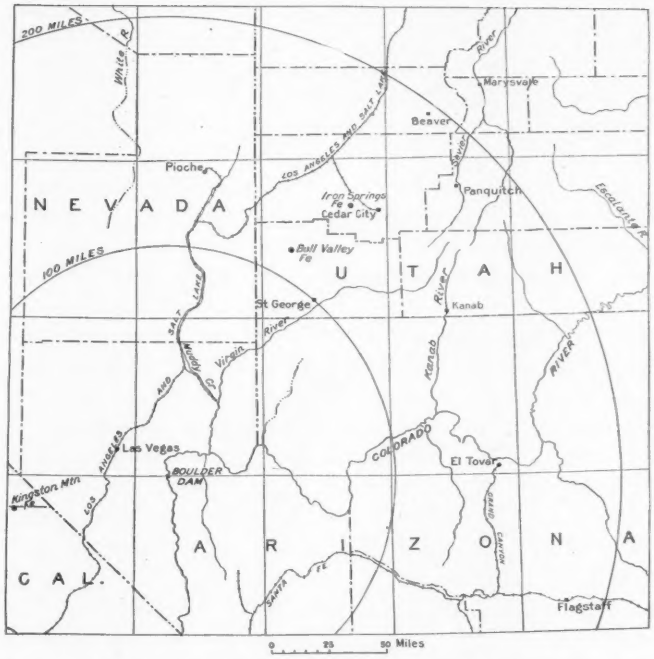


FIG. 1. Map of the lower Colorado River drainage basin, showing ferrous metal mineral deposits tributary to Boulder Dam.

GENERAL GEOLOGY.

The Bull Valley district is completely surrounded by volcanic rocks that constitute the main mass of the Bull Valley Mountains and extend eastward with some interruptions to the Iron Springs district. A thickness of several thousand feet of lavas and tuffs that range in composition from basalt to rhyolite are exposed within the confines of the district. These rocks may be divided into two groups: an older group composed largely of flows, and a distinctly younger series composed largely of rudely stratified pyroclastics capped by rhyolitic tuffs and flows. The volcanic rocks are largely porphyritic latites. At Bull Valley

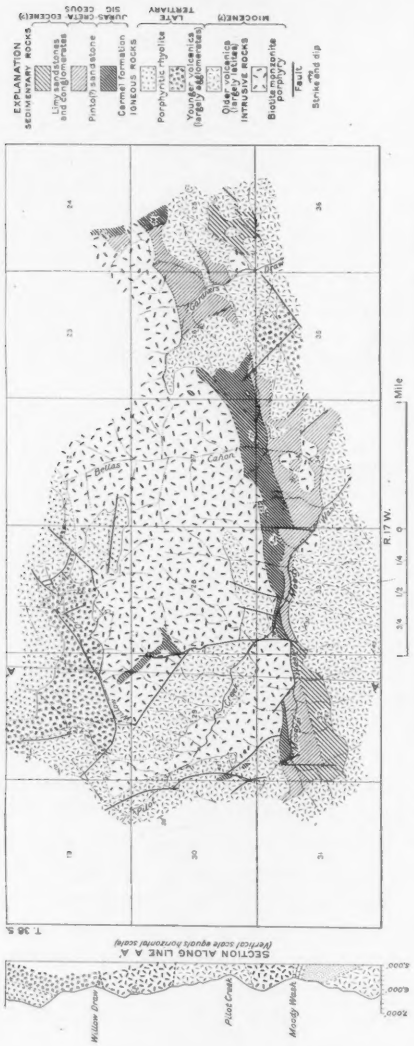


FIG. 2. Geologic map and section of the Bull Valley district, Utah.

erosion and faulting have uncovered a roughly oblong tract of Jurassic limestones and shales (Carmel formation), Cretaceous sandstones and conglomerates, and Tertiary conglomeratic sandstones. These have been intruded by an elongate plug of biotite monzonite porphyry. The lower part of the older volcanics rest conformably on the Tertiary sediments, but as intrusion and deformation were synchronous with the accumulation of the volcanics, these show progressive unconformity. Deformation consequent on intrusion has sharply flexed the sedimentary rocks. Pre-mineral and post-mineral normal faulting is common. The distribution of the rock is shown in Fig. 2.

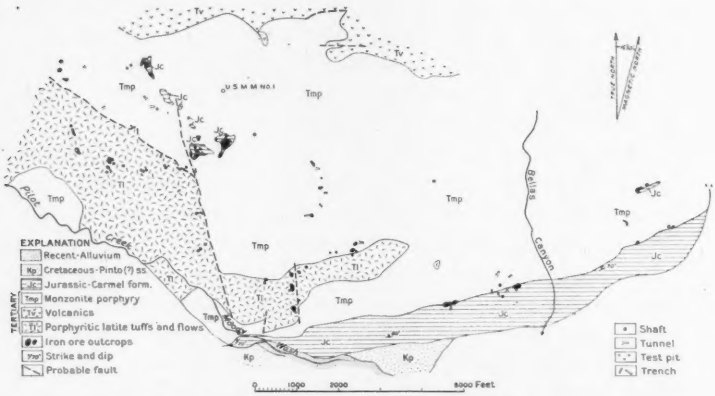
The dominating features of the Iron Springs district are three large intrusions of biotite monzonite porphyry, constituting the Three Peaks, Granite Mountain, and Iron Mountain, which lie in a zone extending northwestward across the district. Three unconformable sedimentary units of Jurassic, Cretaceous, and Tertiary age aggregating 4,000 feet thick crop out in successive rings around these intrusions and dip outward very steeply at the contact, less steeply farther away. Still farther from the intrusive masses nearly horizontal lava flows 2,000 feet thick lie on tilted sedimentary rocks. These general relationships are modified by faulting. Within the monzonite plugs are blocks of partially or completely replaced Jurassic limestones and a few conspicuous veins of massive magnetite and hematite. For further information about the Iron Springs district, the reader is referred to the report by Leith and Harder.

IRON ORE DEPOSITS.

Bull Valley District.

Areal Distribution.—All of the iron ore croppings in the Bull Valley area, with the exception of a small mass of ferruginous chert in tuff at Cove Mountain and a mass of mineralized limestone and latite breccia north of Willow Creek in the SE. ¼ SW. ¼ of sec. 20, are found in an elongate tract about 3 miles long and a mile and one-half wide (Fig. 3). Although float covers

much of the surface, it seems probable that the resistance of both iron ore and the usual contact-metamorphic rocks to chemical and mechanical disintegration would insure their preservation in outcrops or as large debris, and that the mapping, which is largely based on such evidences, shows the general distribution of mineralized rocks.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most of them trend in a northwesterly direction so that they roughly conform to the trend of many of the faults. The largest bodies of iron ore occur in limestone blocks enclosed in monzonite. They occur at altitudes between 6,000 and 6,400 feet. The blocks have been faulted and, as the bedding in them is obscure, it is difficult to determine their attitude. In general the bedding seems to strike toward the northeast and to dip at low angles to the northwest. The largest of the replacement deposits, which lies about 1,000 feet south of Mineral Monument No. 1, has been estimated to contain about ten million tons of ore, according to a magnetometric survey by S. G. Sargis of the firm of Mason, Schlicter and Gauld. In view of the great size of this ore body, it is remarkable that practically no replacement of limestone by iron minerals was found along the main monzonite limestone contact; such ore as was found there fills fissures.

Iron Veins.—A typical iron vein exposed in a pit 1,600 feet west and 400 feet south of Mineral Monument No. 1 is two feet wide and dips 76° NW. It consists of massive black magnetic ore, scattered through which are a few small vugs, some of them lined with imperfect crystals of magnetite. The contact with the monzonite wallrock is sharp and the monzonite shows no alteration. No gangue minerals are visible to the unaided eye. The microscope shows that the primary ore mineral is magnetite, but in places a few laths of hematite have developed along the crystallographic directions (Fig. 4*A*) and in other places the magnetite is almost wholly replaced by solid hematite (Fig. 4*B*).

In the latite tuff the iron ore veins have irregular walls, but there is no evidence of replacement of the wall rock. The ore looks granular, and the weathered outcrops are very rough and vuggy. Quartz crystals commonly occur in the vugs and veinlets of quartz cut the ore. Under the microscope the cavities filled with quartz, and magnetite partly replaced by hematite can be clearly seen in most specimens (Fig. 5*A*).

Iron oxides also occur as interstitial filling in fault breccias and volcanic breccias. An excellent example of breccia cemented by iron oxides is exposed on the east side of Willow Draw in the

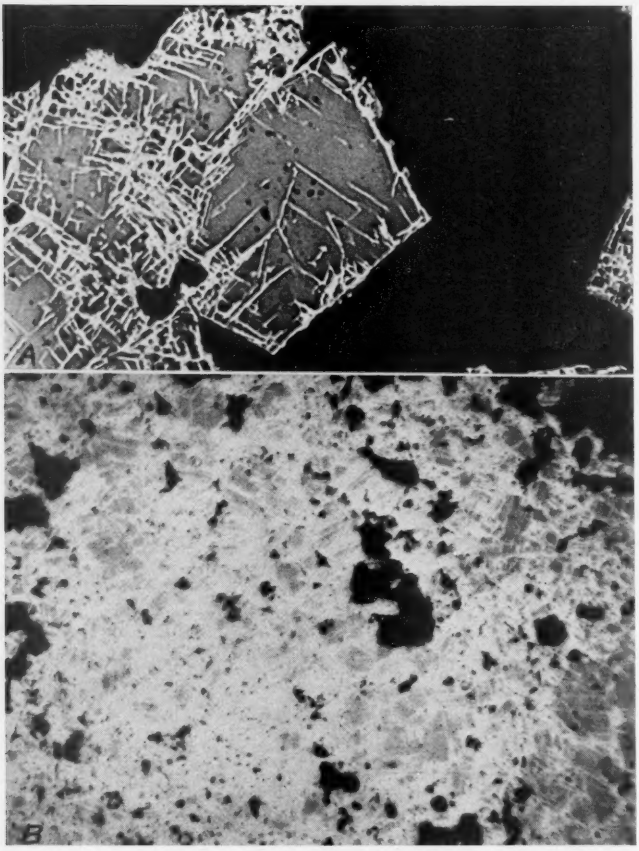

FIG. 4*A*. Photomicrograph of magnetite crystal. Hematite (white) occurs along the crystallographic directions in the magnetite (gray). The crystal is surrounded by quartz (black). ×280. From iron vein 1,600 feet west and 400 feet south of M. M. No. 1.

4*B*. Photomicrograph of magnetite (gray) partially replaced by hematite (white). ×635. From iron vein 1,600 feet south and 400 feet west of M. M. No. 1.

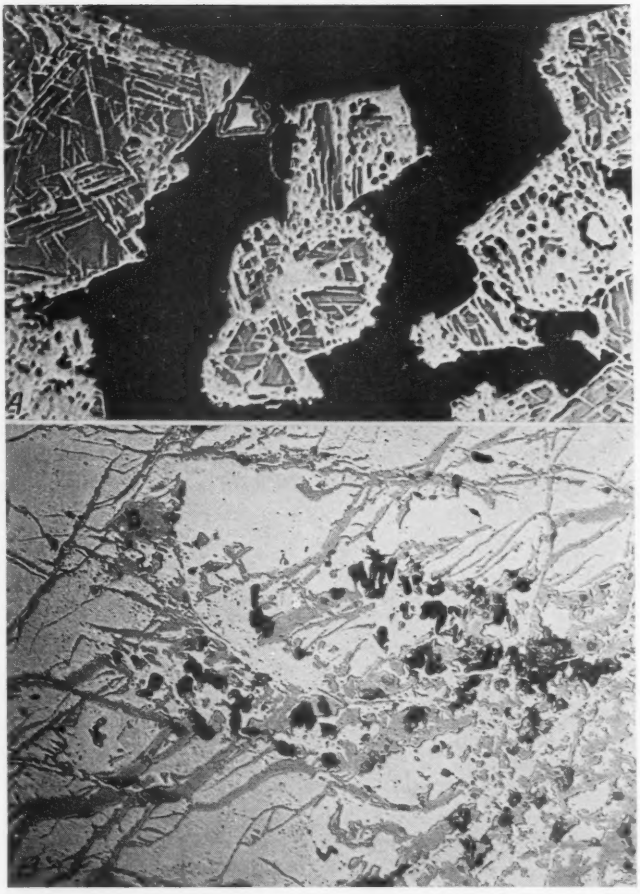

FIG. 5*A*. Photomicrograph showing magnetite (gray) crystals partly replaced by hematite (white) and surrounded by quartz (black). ×635. From iron ore vein in latite tuff, 2,600 ft. west, 1,710 ft. south of M. M. No. 1.

5*B*. Photomicrograph of hematite (white) cut by veinlets of magnetite (gray). The hematite is embayed and shows remnants of hematite in magnetite ×81. From 800 ft. west and 1,450 ft. south of M. M. No. 1.

NE. ¼ of NW. ¼ sec. 29. There a 7-foot vein of specular hematite and magnetite strikes N. 55° W. and dips 74° SW. On the footwall side of the iron ore vein, volcanic breccia adjacent to a fault is cemented with specular hematite for a width of 40 feet. On the west side of the creek precipitous cliffs of volcanic breccia rise 200 feet or more above the creek. This breccia contains considerable iron-oxide cement and is cut by veins containing hematite, quartz, calcite, and augite up to 2 or 3 inches thick. Near the veinlets the mafic phenocrysts have been altered to iron oxide, quartz, and feldspar. Examination of this ore under the microscope reveals euhedral crystals of magnetite lining quartz-filled vugs. The magnetite is partly altered to hematite along crystallographic boundaries.

Leith and Harder [3] mention similar breccias in the Iron Springs district.

Throughout the area, joint surfaces in the monzonite are commonly studded with tiny octahedra of magnetite and at one place with tiny crystals of titanite.

TABLE I.

ANALYSES OF VEINS OF IRON ORE FROM THE BULL VALLEY DISTRICT.
(Analyst, R. E. Stevens, U. S. Geological Survey.)

	A.	*B.*	Probable Minerals.	*A.*	*B.*
FeO	4.55	10.76	Magnetite	14.7	34.6
Fe_2O_3	88.73	73.29	Hematite	78.6	49.4
SiO_2	1.50	12.92	Titanite	0.41	Trace
Al_2O_3	1.17	1.27	Apatite	2.7	Trace
MgO	.81	.22	Pyrite	Trace	Trace
CaO	1.49	.03	Quartz	—	11.5
TiO_2	.17	.08	Clay	3.0	3.2
MnO	Trace	Trace	Water	0.33	—
P_2O_5	1.22	.09			
S	.03	.04			
H_2O	.75	.50			
Total	100.42	99.20	Total	99.74	98.70

A. Ore from vein in biotite monzonite porphyry at 1,600 feet west and 400 feet south of Mineral Monument no. 1.

B. Ore from vein in porphyritic biotite latite at shaft 2,600 feet west and 1,710 feet south of Mineral Monument no. 1.

[3] Leith, C. K., and Harder, E. C.: *Op. cit.*, pp. 69–70, 1908.

Two grab samples of iron ore, one from an iron vein cutting biotite monzonite and the other from an iron vein cutting porphyritic biotite latite tuff, were analysed and the results tabulated below. The percentages of the minerals probably present have been computed and are listed with the analyses.

Replacement Bodies.

Ore in Limestone.—The contact of iron ore and sediments is clearly exposed at only two localities. One is the caved shaft 1,700 feet west and 400 feet north of Mineral Monument No. 1 (Fig. 3). Dense ore is exposed on the west side of the shaft and limestone on the east side; the transition from ore to limestone is abrupt. The second locality is 10,000 feet east and 2,200 feet south of Mineral Monument No. 1, where a long narrow band of sediment is enclosed in monzonite. At the upper contact a layer of limestone is completely replaced by a mass of iron ore about 6 feet wide, which is cut by a few quartz veinlets half an inch or less in thickness. Here also there is an abrupt transition from ore to a hard, gray white and pink, fine-grained limy sandstone with here and there a joint surface studded with magnetite crystals. The lower contact is unmineralized.

In most places the ore of the replacement bodies resembles that of the veins. It consists of dense, massive iron oxide containing small vugs that are lined or filled with clear quartz. In some places the ore shows crystalline structure and the vugs are lined with octahedra of magnetite. Under the microscope all stages of replacement of magnetite by hematite can be seen; in the first stage a few plates of hematite lie along the octahedral planes of the magnetite, and in the last the magnetite is completely replaced by dense hematite. The reverse sequence is found in a specimen of replacement ore from 800 feet west and 1,450 feet south of M. M. No. 1. When examined under the microscope, this specimen reveals hematite cut by veinlets of magnetite (Fig. 5*B*). A thin section and polished surface of ore from the occurrence at 10,000 feet east and 2,200 feet south of the Mineral Monument differs somewhat from most of the ore. Very little magnetite

could be found and under crossed nicols the hematite extinguishes in large irregular patches. The hematite appears to be broken and the quartz that fills the openings contains a few small grains (.02 mm.) of calcite and some tiny plates of a mineral with moderate birefringence, indices slightly greater than quartz, uniaxial and negative, which may be pyrophyllite, talc, or muscovite. A few small grains of garnet also are present.

In general the ore is dense, fine-grained, and massive. At one place earthy ore was seen, and a massive outcrop of iron ore 20 feet wide and 100 feet long, 2,200 feet east and 1,600 feet south of Mineral Monument No. 1 shows bedding and drag folding in the beds.

Two grab samples of replacement iron ore were analysed and the results are shown in Table II. The percentage of the minerals probably present has been computed and are listed with the analysis.

TABLE II.

ANALYSES OF REPLACEMENT IRON ORE FROM THE BULL VALLEY DISTRICT.
(Analyst, R. E. Stevens, U. S. Geological Survey.)

	A.	*B.*	Probable Minerals.	*A.*	*B.*
FeO	0.97	0.83	Magnetite	3.02	2.32
Fe_2O_3	79.72	92.92	Hematite	77.62	72.7
SiO_2	10.28	1.41	Limonite	—	21.6
Al_2O_3	4.69	.79	Clay	11.8	2.0
MgO	1.01	.80	Quartz	4.92	—
CaO	.79	.05	Apatite	0.7	Trace
TiO	0.20	.08	Pyrite	0.15	0.20
MnO	Trace	Trace	Oxides not used	1.80	1.70
P_2O_5	0.29	.07			
S	0.08	.10			
H_2O	1.78	3.42			
Total	99.81	100.47	Total	100.01	100.52

A. Replacement ore showing bedding structure from dump 2,200 feet east and 1,800 feet south of Mineral Monument No. 1.

B. Replacement ore from saddle 800 feet west and 1,400 feet south of Mineral Monument No. 1.

Alteration of the Sediments.—At no place are the sedimentary rocks contiguous to the main intrusive mass of monzonite porphyry exposed. If the sedimentary rocks along this contact had

been baked or metamorphosed for a width of more than a few inches, it seems probable that the indurated product would crop out or be readily found in the float. Therefore it is reasonable to suppose that the rocks did not undergo such alteration. Outcrops of sediments within 25 feet of monzonite porphyry in place show little or no alteration. At a few places the rock is slightly bleached or cut by veinlets a fraction of an inch thick of quartz, calcite, and iron oxide, and a few small fragments of red and white spotted shale (less than 3 inches in largest dimension) were found at one locality. The alterations thus shown can hardly be regarded as contact metamorphism.

The masses of limy sandstone and shale included in the monzonite porphyry show varying amounts of alteration and recrystallization. In a thin section of a shaly rock containing detrital feldspar from one of these inclusions, incipient development of a micaceous mineral was the only evidence of contact metamorphism recognized under the microscope.

The megascopic features developed by alteration of limy shale beds is best observed in an adit in a gully 1,410 feet south of Mineral Monument No. 1. The adit is 85 feet long and from the portal to the breast passes through the following sequence of rocks:

10 feet	Thinly banded limestone which has been broken into blocks and shows narrow veins of iron oxide.
2 feet	Crumbly brown iron oxide.
25 feet	Mottled, lumpy, friable rock with a pseudo-pisolitic structure caused by the tendency of the rock to break into small roughly spherical pellets. The rock has a bleached appearance. No bedding was observed.
30 feet	Altered shaly limestone, marked with brownish gray and greenish gray bands from 3 mm. to less than 1 mm. thick.

Along some bands lenses lined with hemiprisms of a nonaluminous monoclinic pyroxene, olive green, non-pleochroic, $\alpha = 1.682$, $\beta = 1.690$, $\gamma = 1.710$, $2V = 65° - 70°$, Birefringence $= 0.028$, were observed. All the bands show specks of iron magnetite, hematite, or limonite when examined with the hand lens.

Examinations of these altered calcareous shales or mudstones under the microscope shows that they have been little altered;

in most specimens only a few new minerals have been developed, and in no specimens is the rock largely recrystallized. Most of the new minerals with the exception of the iron oxides have been developed contiguous to cracks or around former pore spaces. Heulandite is the most abundant of the new minerals. It is found in the difficulty resolvable clay-like material as small areas with irregular boundaries. In parts of the thin sections several of the heulandite areas show simultaneous extinction. Similar areas of calcite and more rarely analcite were observed. Indefinitely bounded areas in the heulandite have higher birefringence and probably are areas that have been altered to muscovite. Tiny euhedral to anhedral crystals less than 0.01 mm. in size are scattered through the thin sections. They are too small to be determined but because their relief and birefringence resemble those of the larger pyroxene crystals they are believed to be the same mineral. In some places they form bands largely replacing certain layers. In many thin sections intermeshed prisms of pyroxene form bands or clusters along some layers and comb structures along tiny fissures. The centers of some comb-lined veinlets are filled with calcite, heulandite, or chabazite. Magnetite and hematite are present throughout and range in abundance from scattered subhedral or anhedral grains to aggregates of grains which in places completely replace thin layers of the original rock. Not uncommonly a band of iron grains shows a pinching and swelling median zone which consists mainly of prisms of augite with a few of apatite. These minerals are surrounded by heulandite or analcite both of which are partially replaced by calcite.

Some very finely granular portions of these rocks consist of a mixture of tiny grains of quartz and pyroxene.

A more intense metamorphism was found in a specimen of iron ore found on a dump. The source of the specimen is not known, but a drag fold in the original bedding structure can be seen. The predominant gangue mineral in this specimen is albite.

Alteration of Biotite Monzonite Porphyry.—In general no alteration of the monzonite porphyry can be observed at its con-

tacts. Where the porphyry had been shattered prior to mineralization, however, as for example on Willow Creek in the NE. of NW. sec. 29, the porphyry is cut by small veinlets containing calcite, augite, magnetite, and a little quartz. The rock has a greenish hue, imparted by clusters of tiny light green augite prisms scattered through the groundmass and by aggregates of these crystals which have replaced some of the original mafic phenocrysts. Most of the feldspar phenocrysts are quite unaltered, but some are altered to granular aggregates of quartz and feldspar with a little calcite. It has been impossible to determine what part of the alteration in the sediments and the contiguous biotite monzonite porphyry was produced by the constituents of the intruded plug and how much was produced by the mineralizing emanations that introduced the bulk of the iron from a deeper source.

Iron Springs District.

In October 1935, the writer made a brief visit to the three pits that have been opened up at Desert Mound, and in October 1936 spent part of a day at Iron Mountain examining the Black Hawk pit, which had been opened up during the preceding twelve months. As these workings offer better opportunities to examine the occurrence of the ore than were available when Leith and Harder studied the area, brief descriptions of the pits are given below.

Working at Desert Mound.

The three pits at Desert Mound are in an elongate ore body that has a general east and west trend, low dip to the south, and crops out on the north slope of the Mound. The ore body has been cut into large blocks displaced either to the north or south by faults that strike either slightly east or west of north. The shape of the ore body at right angles to its long dimension is shown in Fig. 7.

Milner Pit.—The Milner Pit, located on the northwest end of the exposed ore body, is about 500 feet E–W and 400 feet N–S,

and has a maximum depth of 150 feet. Its bottom is in iron ore. The upper part of its walls, which are mostly inaccessible, consist of well-bedded limy shales and sandstones, white, gray, and olive-green in color, which dip about 20° to the south. The upper contact of the ore is horizontal and cuts across the bedding at an acute angle (Fig. 6). The beds and the contact are much

FIG. 6. Photograph of Milner Pit, looking east, Desert Mounds, Utah. Note southward dip of sediments and boundary of ore cutting across beds.

faulted. The ore in the pit is for the most part powdery, porous and vuggy; some compact masses are found, but none of them are large. The layer of the original beds, which was very wavy, is clearly preserved in much of the ore. Incrustations of jarosite are common. The churn drill holes (Fig. 7) pass through barren rock, and then abruptly to a layer of low-grade ore about 40 feet thick. Beneath this lies a layer of high-grade ore about 125 feet thick, which apparently is underlain by biotite monzonite porphyry on a horizontal contact.

The part of the ore body within the confines of the King and Contact claims originally contained about 7,000,000 tons of ore,

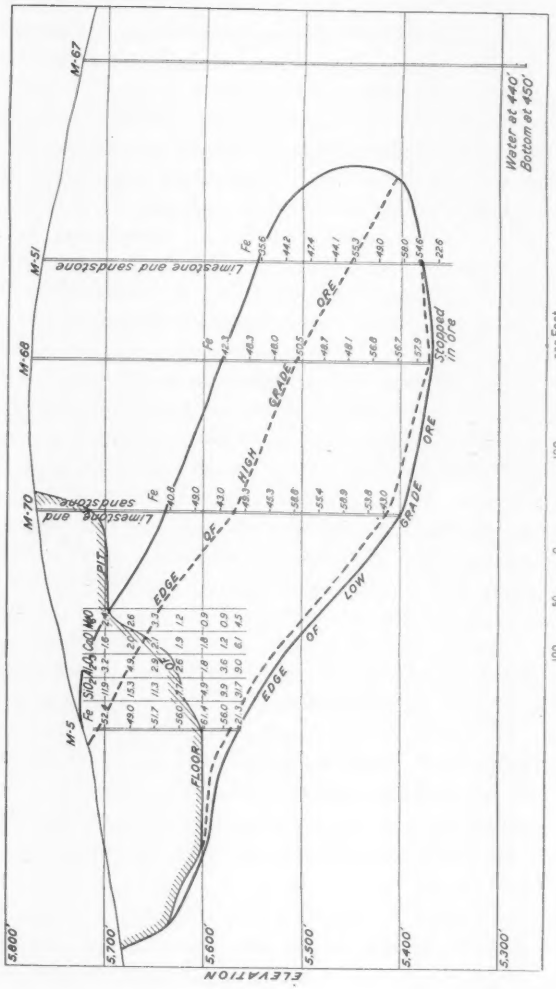

FIG. 7. North south section through Milner Pit showing analyses of samples taken at 25 foot intervals in churn drill holes.

only part of which, however, can be mined from the open pit. Examination of the chemical analyses of the churn drill samples show that decrease in iron content is accompanied by marked increases in silica and alumina.

C. F. and I. Pit.—The C. F. and I. pit is situated about 700 feet east of the Milner pit on the east side of a large ore body. The pit measures about 500 feet east-west and 450 feet north-south. In some places the sedimentary rock next to the ore is cherty, at others it is recrystallized limestone. Some gray, dense, calcareous mudstone showing inconspicuous color banding has fallen into the pit from the overlying beds. The microscope reveals little recrystallization in the mudstone; some definitely crystalline calcite is present though most of the material is too fine grained for identification. Some small areas of quartz with sutured boundaries and veinlets of calcite with comb structure, also a few scattered cubical grains of limonite, probably pseudomorphs of pyrite, are present. About 80 percent of the material is insoluble in dilute HCl. The iron ore is finely crystalline and dense and the microscope reveals almost complete replacement of magnetite by hematite. The structure of the deposit is complicated by faulting and has not been completely worked out.

Upper Ore Pit.—The upper ore pit is situated between the Milner and C. F. and I. pits on the north edge of the same ore body. The pit is only 30 feet deep and is in ore from the surface to the bottom. The ore is fine-grained and dense and much of it is brecciated.

A large body of ore, called the Short Line Ore Body, lies to the north and west of these deposits beneath the alluvium. Geophysical measurements and some drilling by private parties indicate that there is about 2,000,000 tons of ore in this body.

Workings on Iron Mountain.

General Statement.—Many large bodies of iron ore crop out around the periphery and in roof pendants within the Iron Mountain monzonite porphyry stock. Large fissure veins of massive magnetite and hematite as much as 20 feet wide and 2,000 feet

long traverse the monzonite. The masses are mostly tabular, somewhat curved, tapered at one or both ends, and almost invariably branching, and are accompanied by subsidiary parallel masses. Their orientation is diverse; in general, they follow the direction of the adjacent jointing and faulting.

The Blow Out, a knob of massive magnetite and hematite on the south flank of the mountain, is carved from a large replacement body, for a description of which the reader is referred to Leith and Harder.[4]

Black Hawk Pit.—The Columbia Steel Corp. has explored its claims on the south flank of Iron Mountain by electromagnetic survey and churn drilling and delimited 3 large ore bodies, the Pinto, Black Hawk, and Duncan. In October 1936, the southwest end of the Black Hawk ore body was opened up. The northeast wall of the pit is in massive iron oxide, in which are small drusy cavities, lined with clear quarz crystals, from which irregular quartz stringers extend into the ore. The northwest wall of the pit consists of monzonite porphyry separated from the ore by 20 to 40 feet of sedimentary rock that shows much iron oxide. The contact of the sedimentary rock with the iron ore is vertical and sharp and may mark a fault. The southeast wall of the pit consists of monzonite porphyry, whose contact with the ore is also vertical. The monzonite is stained with iron oxide for a distance of 30 feet from the contact and shows signs of hydration. The iron-stained rock is succeeded by white, friable rock, clearly showing the texture of monzonite porphyry.

Ore and Associated Gangue Minerals.

Mineralogy.—Magnetite, hematite, limonite, apatite, jarosite, quartz and chalcedony were the only minerals observed in the iron ores from the Iron Springs district. Barite, calcite, galena, siderite, and chalcopyrite were observed in a small prospect tunnel.

According to Cooke,[5] who made concentration tests on the ore from Desert Mound:

[4] Leith, C. K., and Harder, E. C.: *Op. cit.*, p. 69, 1908.

[5] Cooke, S. R. B.: Amenability of various iron ores to rigorous concentration. U.S. Bur. of Mines Rept. of Invest. 3229, p. 13, 1934.

The ore is strongly magnetic but contains sufficient hematite and limonite to hide the presence of magnetite from the naked eye. A study of the nonmagnetic tailings obtained by magnetic concentration of the crushed ore showed the presence of muscovite, apatite, quartz, calcite, dolomite, chalcedony, and limonite. The quartz is coarse to fine in structure and generally is finely locked with the ore minerals. Muscovite is abundant and is associated with the quartz. The apatite is small in quantity, and its association with the ore minerals could not be ascertained by microscopic means. The chalcedony is massive and banded. Calcite and dolomite occur as rather large crystals locked with the silicate minerals. The magnetite is fine-grained and has crystallized in particularly well-defined euhedra. It is normal in hardness and color. . . . The chalcedony has been introduced subsequently to the magnetite for the rhythmic banding in the former is parallel to the outlines of the magnetite grains.

The magnetite content of the ores as determined by magnetic concentration is variable. It ranges from about 2 per cent to 23 per cent, with an average content of 14 per cent at Desert Mound. At Iron Mountain there seems to be a belt in the Black Hawk ore body where the magnetite content exceeds 50 per cent. The average for this ore body is about 33 per cent. For the Burke ore body at Iron Mountain the average appears to be 50 per cent. A large body of ore at depth south of the Black Hawk ore body was determined by magnetometric survey; this ore body, on the basis of calculation, appears to be 10 per cent magnetite.

Samples of ore from Bull Valley, Iron Mountain, and Desert Mound were analyzed for zinc in the laboratory of the Columbia Steel Corporation but none was found.

In the chapter entitled "Kind and grades of ore," Leith and Harder [6] mention all the minerals listed by the writer with the exception of jarosite, and state further:

At the surface the ore is ordinarily hard crystalline magnetite and hematite in porous gnarled and contorted masses with coarsely crystalline quartz and fibrous chalcedony as the principal gangue minerals filling wholly or partly cavities in the ore. Other gangue minerals occurring in small practically negligible amounts are apatite, mica, siderite, diopside, garnet, pyrite, chlorite, calcite, barite, galena, amphibole, copper carbonates, limonite, and amethyst. Of these minerals barite and galena are more closely associated with the limestone than with the ore. Melanterite, associated with pyrite, was found in process of formation in the long tunnel on the Duncan claim. Beneath the surface the ore is usually softer and contains a larger proportion of soft, bluish, reddish, brownish, grayish, and greenish banded hematite, limonite, and magnetite in greatly

[6] Leith, C. K., and Harder, E. C.: *Op. cit.*, p. 70, 1908.

varying proportions and relations. The gangue materials are more abundant than near the surface, and calcite is in relatively increased proportion as compared with the quartz. The banding in the contact ores partly represents the bedding of the limestone, which as will be shown later, the ore replaces.

It seems probable from statements on page 84 and the table on page 85 of the Leith-Harder report that pyrite, barite, galena, siderite, and copper carbonates are not associated with the iron ore, but the text is not clear.

Minerals Developed at the Contact.—Although the writer examined only a small part of the many miles of intrusive contact in the Iron Springs district, he had an opportunity to study the alteration of the sediments at several places adjacent to large ore bodies, where they are well exposed in pits. None of the usual contact silicate minerals were found. In discussing the alteration observed in the limestone, Leith and Harder [7] say:

> The limestone adjacent to the andesite has been locally replaced by iron ore and has been generally vitrified, silicated and kaolinized in bands usually not more than 60 feet wide. . . . The principal minerals are albite, kaolin, actinolite, diopside, quartz, orthoclase, serpentine, phlogopite, andradite, iron ores, osteolite, andalusite, wollastonite, calcite, etc., varying greatly in proportion in different places but usually occurring in quantity in the order named. They are found in veins in breccias, and disseminated through the rock.

TABLE III.

ANALYSES OF SAMPLES FROM CHURN DRILL HOLE NO. 86, AT IRON MOUNTAIN (ALTITUDE 6,630).

(Analyses furnished by Columbia Steel Company.)

Depth.	Fe.	SiO_2.	Al_2O_3.	CaO.	MgO.	P.	S.	Totals.[8]
0–45′				Limestone				
45–50	15.7	34.7	8.1	7.2	2.9	.21		68.8
50–55	36.3	30.0	6.7	1.7	1.0	.21		75.9
55–60	49.8	11.2	3.30	4.68	2.0	.19	.016	71.2
60–65	54.4	10.1	3.03	4.16	1.74	.30	.018	73.8
65–70	52.4	11.1	3.13	4.88	1.47	.21	.015	73.2
70–75	41.9	16.7	4.3	3.4	1.2	.42		67.9
75–80	17.0	27.6	11.2	2.2	2.2	.18		60.4
80–85	9.5	40.0	12.2	5.5	3.2	.21		70.6

[7] Leith, C. K., and Harder, E. C.: *Op. cit.*, p. 25, 1908.

[8] Note iron is not given as an oxide. If the iron in the sample from 60–65 feet is figured as Fe_2O_3, the summation is 97.0%.

Although locally minor amounts of silicates have been developed in the limestone as indicated by Leith and Harder's description, the greater exposures afforded by development at the present time tend greatly to minimize the distribution and degree of the silicate metamorphism especially in comparison to the size of the known ore bodies in close proximity to the limestone.

Analyses of the drill cores (Fig. 7 and Table III) would indicate that very little material other than iron has been added to the sediments, for decrease in iron content is always associated with increase in silica, lime, alumina, and magnesia. Alumina is rarely transported, so it seems reasonable to assume that the present differences in composition represent differences in the original sediment. Leith and Harder [9] likewise came to the conclusion that "in general there has been large loss of material from the limestones at the contact without conspicuous introduction of new material except soda, but that exceptional phases show clearly the introduction of silica and iron."

ORIGIN OF THE DEPOSITS.

As the deposits in the Bull Valley and Iron Springs districts occur in limestone at intrusive contacts, they could be classified as contact-metamorphic deposits; and Leith and Harder so classified the deposits of the Iron Springs quadrangle. Though Lindgren [10] has suggested the term pyrometasomatic deposits for contact-metamorphic deposits, the older term will be retained here because of its use by Leith and Harder and others in discussions of the deposits of this region.

In a discussion of the contact metamorphism at Yerington, Nevada, Knopf [11] concludes, "The one distinctive feature of the contact-metamorphic group, then, is the association of metalliferous minerals with contact silicates."

In the following pages, only the alteration associated with the

[9] Leith, C. K., and Harder, E. C.: *Op. cit.*, p. 34, 1908.

[10] Lindgren, Waldemar: A suggestion for the terminology of certain mineral deposits. ECON. GEOL., vol. 17, p. 293, 1922.

[11] Knopf, Adolph: Geology and ore deposits of the Yerington district, Nevada. U. S. Geol. Surv. Prof. Paper 114, p. 46, 1918.

ore-forming processes is considered. The deposits of the Bull Valley and Iron Springs district differ from the usual contact deposits in the following respects:

(1) The heavy silicate minerals which in typical contact deposits are far more abundant than the ore minerals and generally occur in continuous aureoles whose areas of outcrop are to be measured in square miles, are here of merely sporadic occurrence and do not occur in the ore.

(2) Sulphide minerals were not seen in the main ore bodies either at Bull Valley or Iron Springs, and they were found at only one locality in the lavas at Iron Mountain. A little jarosite at C. F. and I pit, Desert Mound, may indicate the presence of some pyrite in depth.

(3) The usual hydrothermal gangue minerals were observed only at this same locality.

(4) Massive hematite-magnetite fissure veins, best exemplified in the Iron Springs area where veins as much as 20 feet wide and 2,000 feet long occur, cut both the monzonite and the latite.

(5) Alteration is largely absent from the intrusive rock and almost totally from the overlying volcanics.

(6) Neither dikes nor quartz veins were observed.

(7) The hematite and magnetite are not distributed through the limestone but are restricted to ore bodies that have abrupt transitions through a narrow crumbly silicified zone to the pure unaltered limestone. Individual replacement bodies of the magnitude of ten million tons of ore, most of which assay in excess of 50 per cent iron and all of which assay in excess of 40 per cent iron, are known, and the total tonnage of such bodies in both the Iron Springs and Bull Valley districts is probably of the magnitude of 100,000,000 tons.

(8) Although the limy shales and shaly limestones are locally baked along their contacts with monzonite, where some fine-grained augite, muscovite, chabazite, apatite, and calcite have been developed, the amount of baking and of recrystallization in the more massive limestones is very limited. Apparently, no element other than iron was added to the pure limestones except for

minor amounts of soda added locally that are insignificant in proportion to the bulk of the iron ore as previously stated.

The following deductions concerning the process of mineralization can be derived from these facts. A temperature of 500°–600° C. (the range of temperature given by Zies [12] for the formation of magnetite from the gases) prevailed along the fractures in the monzonite and presumably in highly fractured portions of the adjacent limestone. The limestone, however, shows little evidence of bleaching, or even simple recrystallization. Clark [13] cites data showing that limestone may be recrystallized at such temperatures, but the control of the experiments was so indefinite that the limiting conditions were not determined. Although it can not be definitely stated that the absence of recrystallized limestone, except for narrow areas along the contact indicates that the limestone in general did not reach any such temperature, the well known tendency of limestone to be bleached or recrystallized supports such an inference.

The emanations contained but few elements, and iron was the only metal carried by them in large amounts. Examination of Fig. 8 shows that of the chlorides of the common rock-forming elements and the more common metals only $FeCl_3$ and $AlCl_3$ have a vapor pressure as high as one atmosphere at 600° C. or less. The transfer of aluminum chloride as gas in the presence of excess water vapor is prevented by its tendency to hydrolyze; the system water vapor-chlorine-iron has not been completely worked out, but it has been demonstrated in the laboratory that gaseous ferrous and ferric chlorides can exist associated with hydrogen chloride, chlorine, and water vapor above 550° C.[14] Silica can be transferred in the vapor phase with water gas at high temperature and pressure, especially if other volatiles are present,[15]

[12] Zies, E. G.: The Valley of Ten Thousand Smokes; the fumarolic incrustations and their bearing on ore deposition. Nat. Geog. Soc., Contributed Technical Papers, Katmai ser., vol. 1, no. 4, pp. 7–10, 1929.

[13] Clark, F. W.: The data of geochemistry. U. S. Geol. Surv. Bull. 770, p. 563, 1924.

[14] Zies, E. G.: *Op. cit.*, pp. 7–11, 1929.

[15] Greig, J. W., Merwin, H. E., and Shephard, E. S.: Notes on the volatile transport of silica. Am. Jour. of Sci., vol. 25, pp. 71–73, 1933.

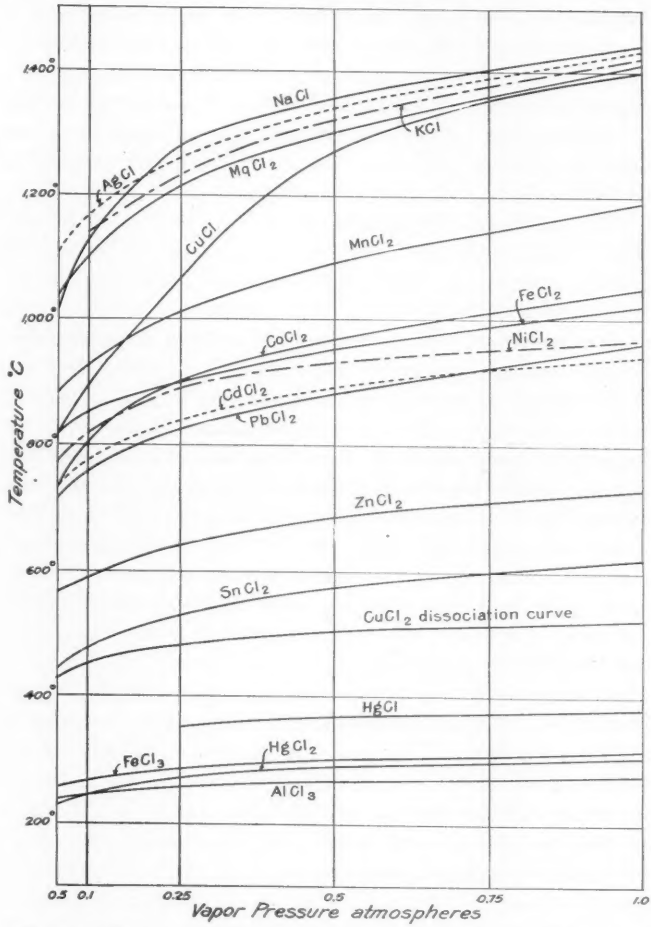

FIG. 8. Vapor pressure-temperature graph of the chlorides of the common rock-forming elements and chlorides of some metals. Data from Maier.

"Vapor pressure of the common metallic chlorides and a static method for high temperature." U. S. Bur. of Mines, Tech. Paper 360, pp. 1–54, 1925.

but the amount of transfer is probably very small. Vapor transfer then could effect the transfer of iron without other material.

The scarcity of silica in the iron deposits of this region is thought to indicate that little of the mineralization was effected by solutions that left the magma in the liquid phase, for most liquid hydrothermal solutions are known to carry silica and to deposit it under a great variety of conditions.

The character of the deposits seems to be explainable by supposing that they were formed, in openings at shallow depths, chiefly by solutions in the gaseous phase, but that these solutions, because of a rapid fall of temperature, passed to the liquid phase, in which, however, they were active only for a relatively brief period. The openings must have been of such a character that they permitted the ready egress of gases under very slight pressure to the surface. The cover at the time of formation of the iron deposits could not have exceeded 4,000 feet in the Bull Valley area. Leith and Harder [16] estimate that the thickness of the cover of sedimentary rocks in the Iron Springs area was about 4,000 feet. According to the interpretation of the writer, part or all of the 2,000 feet of lavas were present in the Iron Springs area at the time of mineralization. This would increase the cover to at most 6,000 feet. The structures of both areas indicate that tension fissures were present.

Incrustations of magnetite and hematite are common products of vulcanism.[17] Zies [18] has shown that magnetite and hematite have been deposited as fumarolic incrustations from ferrous and ferric chloride and water gas. He says,[19] "It seems quite probable that magnetite will form when steam reacts with the two chlorides provided the temperature is in the neighborhood of 550° C." Such temperatures were observed at fumaroles in the Valley of Ten Thousand Smokes. It has been demonstrated [20] that magnetite can be converted to hematite by hydrogen chloride gas.

[16] Leith, C. K., and Harder, E. C.: *Op. cit.*, p. 77, 1908.
[17] Wolff, F.: Der Vulcanismus, p. 593, Stuttgart, 1914.
[18] Zies, E. G.: *Op. cit.*, p. 5, 116, 1929.
[19] Idem, p. 8.
[20] Idem, p. 10.

Deposition from a gaseous phase at high temperature explains all the features of the magnetite-hematite veins, including the absence of the usual hydrothermal gangue minerals and of sulphides which, according to Allen and Zies,[21] are deposited at lower temperatures.

This explanation, when applied to the replacement of limestone, meets with a difficulty, however, in that none of the compounds of calcium are volatile at the assumed temperature, although Fenner cites volcanic sublimates of calcium as well as an experiment by Fouqué as evidence in support of gaseous transfer of this element.[22] A change of calcium carbonate to calcium chloride, mole for mole, would entail an increase of volume,[23] and if calcium chloride is the product formed, no space will be developed in which to deposit iron oxides unless some material is removed. Experimental evidence shows that $CaCl_2$ in the presence of H_2O tends to change to CaO. Without trying to set up all the reactions, it seems that even in the presence of HCl, $CaCO_3$ breaks down to CaO with escape of CO_2 and diminution of volume of about 40 per cent. The remaining space could be filled by magnetite which is formed above 500° C.[24] The writer can conceive of no method for calcium removal except transport by a liquid phase, even though this phase be only present as droplets carried by rapidly streaming gas, a process only possible along appropriate channels. The maximum temperature at which liquid could exist, assuming a hydrostatic pressure equal to a 6,000 foot water column, is 350° C. The great solubility of calcium chloride insures its immediate removal as soon as the liquid phase appears. Though the formation of the iron deposits in limestone requires a liquid phase, all the evidence indicates that the material left the magma as gases to condense later. This

[21] Zies, E. G.: The fumarolic incrustations and their bearing on ore deposits. Nat. Geog. Soc., Contributed Technical Papers, Katmai ser. vol. 1, no. 4, pp. 11–12, 1929.

[22] Fenner, C. N.: Pneumatolytic processes in the formation of minerals and ores. Ore deposits of the Western States, pp. 84–85, A. I. M. E., New York, 1936.

[23] Mellor, J. W., A comprehensive treatise on inorganic and theoretical chemistry, vol. III, p. 714, Longman & Co., London.

[24] Zies, *op. cit.*, p. 8, 1929.

liquid phase differs essentially from the magmatic hydrothermal phase as it carries but few of the elements found in hydrothermal deposits, and under the conditions assumed did not come into existence until after the water gas had left the magma.

Burbank [25] has recently given an illuminating analysis of the related phenomena of igneous intrusion, vulcanism, and ore deposition, and has postulated a source of heat in the oxidation of the components of the magma, the oxidation of iron from the ferrous to the ferric state being one of the most important. The parts of his analysis that are pertinent to this problem are briefly summarized as follows: Fracturing of the upper, solidified portion, or "hood" of the magma suddenly releases pressure in the subjacent solid-liquid system, permitting rapid evolution of gas. The evolution of gas causes freezing in some direct proportion to the amount of gas evolved and in inverse proportion to the amount of heat generated by the consequent oxidation. For discussion, the magma from the solid part of the "hood" downward can be divided into three zones, which merge from one to the other; a zone where the heat generated by oxidation is less than the heat-loss through evaporation, so that crystals form; a zone of maximum heat generation with evolution of gas and remelting of some of the solid phase; and a zone of transition to the underlying magma in which gas is not greatly concentrated. The rapid crystallization in the first zone quickly forms a solid mantle that may soon become strong enough to build up a back pressure, which stops volatilization. The gas phase is therefore episodic, of brief duration, and it forms a break in the mineral paragenesis which Burbank calls a "mineral unconformity." A tapering cupola of a flat-topped magma-body being impelled from below may reach a point in the surface of the earth where vulcanism will be initiated.

> . . . If the excess energy is fairly great, comparatively quiet eruptions would result, and the magma would flow as lava from the volcano. When most of this is expended, a magma-hood would form in the throat of the

[25] Burbank, W. S.: A source of heat-energy in crystallization of granodiorite magma, and some related problems of vulcanism. Am. Geophys. Union Trans., 17th Ann. Meeting, pp. 236–255, National Research Council, Washington, D. C., 1936.

volcano and would grow downward indefinitely unless crustal disturbances occurred. If fracturing or relief of pressure occurred because of tidal stresses or local weakness of the crust, and sufficient excess energy still resided in the rock, the evolution of gas from the magma-fraction and the heat of oxidation might cause the development of pressures that would exceed the strength of the overlying and surrounding crust. A series of explosions would result and the magma-hood would be largely destroyed by its own potential energy. The first explosion would cause immediate release of pressure upon lower parts of the magma-column within which the freezing factor approximated but slightly exceeded the value of the oxidation-factor, and this second quickly formed hood would explode in turn. This would continue until such depth in the magma-hood and column was reached that the forces were no longer able to disrupt the overlying crust or until the oxidizing factor became prominent, when a considerable amount of remelting might occur. . . .[26]

The igneous history at Bull Valley, briefly outlined below, closely parallels the sequence of events postulated in this hypothesis.

Igneous activity in the area started with the extravasation of rhyolite flows and the eruption of rhyolite tuffs, probably derived from a small fraction in cupolas of a large subjacent pluton, the upper part of which had reached the composition of a monzonite. The vent from which these were derived may have lain to the north of Bull Valley. Latite magma next rose in the cupolas and was poured over the surface in great quantities, forming the most abundant effusive in the region. Monzonite porphyry formed in part of the vent in the Bull Valley area and this was pushed up as a plug, deforming the strata, while latite was still reaching the surface. Finally a gaseous phase was again evolved with the formation of latite tuff, followed again by extravasation of latite, which closed this cycle. The absence of dikes or quartz veins indicates that the products of the later igneous activity did not reach the area.

Further evidence for the hypothesis is found in the petrography of the igneous rocks. Crystal melting is shown by the presence of partially resorbed phenocrysts in many of the flows. Oscillatory zoned plagioclase crystals are common in the flows. According to Phemister [27] zoning can be produced by the following

[26] *Op. cit.*, p. 248.

[27] Phemister, James: Zoning in plagioclase feldspar. Min. Mag., vol. 23, p. 553, 1934.

factors: movement of crystals in the magma, movement of magma as a whole into a region where different conditions of temperature or pressure prevail, eruption of additional magma into a crystallizing liquid and loss of volatile constituents, all incidents which are probable events in magma that is awaiting eruption.

A high degree of oxidation in all the rocks analyzed is indicated by the ratio of ferric to ferrous oxide, which is always in excess of two to one whereas the ratio of these oxides in the average monzonite and latite given by Daly [28] is about one to two. Several percent of iron oxides is present in most of the igneous rocks. The abundant development of biotite, generally 7 or 8 percent, high in iron, indicates the presence of much water vapor and ferric oxide. The abundance of volatile components is further shown by the numerous tuffs, especially a welded tuff or ignimbrite. Such tuffs are believed to be formed by Nuée ardente,[29] which, according to Perret [30] are formed by the explosive expansion and consequent complete pulverization of a magma high in volatiles.

From the preceding discussion it seems probable that water vapor and the chlorides of iron formed the bulk of the emanations. They left the magma in the gas phase during one major episode of the history of magmatic crystallization and emplacement. During most of this episode the gases did not condense within the rocks now present. As these deposits were never subjected to the hydrothermal phase of mineralization, they preserve their original simple mineral character.

SUMMARY.

The iron ore deposits of the Bull Valley and Iron Springs districts, Utah, consist of veins of magnetite and hematite in monzonite and magnetite-hematite replacement bodies in limestone.

[28] Daly, R. C.: Igneous rocks and depths of the earth, p. 13, New York, 1933.

[29] Marshall, P.: Acid rocks of the Tampo Rotura district. Roy. Soc. of New Zealand Trans., vol. 64, pp. 1–70, 1935.

[30] Perret, F. A.: The eruption of Mt. Pelee, 1929–1932. Carnegie Inst. of Washington, p. 89, 1935.

Neither the ores nor the country rock show the features characteristic of contact-metamorphic deposits. The following explanation of the origin of the deposits is offered. During the intrusion of monzonite porphyry stocks, the hoods and overlying rock were fractured, causing a sudden release of pressure and liberating $FeCl_3$ and H_2O gas from the stocks which were still at high temperature. These gases found ready egress to the surface along tension fissures without appreciably heating the country rock. They deposited magnetite and hematite in the fissures and replaced the contiguous fractured limestone. The period of gas emanation was brief and the hydrothermal phase probably evolved during the later magmatic history never reached this area. The deposits were formed under a cover of less than 5,000 feet.

U. S. Geological Survey,
Washington, D. C.,
February 12, 1938.

MANGANESE DEPOSITS OF THE DRUM MOUNTAINS, UTAH.[1]

EUGENE CALLAGHAN.

ABSTRACT.

More than 15,000 tons of manganese ore has been produced from small deposits in the Drum Mountains in west-central Utah. Lenses of rhodochrosite, now largely weathered near the surface to manganese oxides, lie parallel to the bedding of Cambrian dolomites and shales near faults that are nearly normal to bedding. Two varieties of rhodochrosite, one fine-grained, dark-gray or black, and massive, the other coarser-grained, pink, and generally occurring in veinlets in the gray variety, are present. The gray contains less $MnCO_3$ and $FeCO_3$, but more $CaCO_3$ and $MgCO_3$ than the pink variety. The deposits are interpreted as bodies that replaced favorable dolomite or limestone beds. The gray rhodochrosite first replaced the dolomite or limestone; the pink variety later formed veinlets in the gray rhodochrosite and replaced it to a small extent.

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INTRODUCTION.

As THE manganese deposits in the Drum Mountains of west-central Utah (Fig. 1) have yielded a considerable tonnage of manganese, ore, they deserve a brief record. They are of interest in that they may be interpreted as deposits of rhodochrosite that replace Cambrian dolomite or limestone. Such deposits are rare, as manganosiderite is the usual manganiferous carbonate in de-

[1] Published by permission of the Director, Geological Survey, United States Department of the Interior.

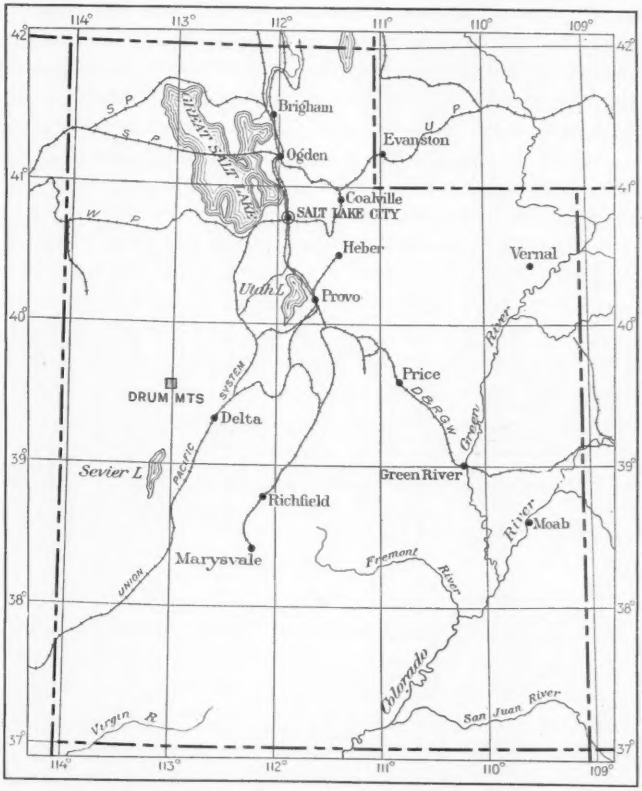

FIG. 1. Index map of Utah showing location of Drum Mountains region.

posits of this type.[2] The purpose of this paper is to point out briefly some of the geologic and mineralogic features of the deposits. Two days in October 1937 were devoted to the field observations.

The Drum Mountains occupy an area of 25 square miles on

[2] Hewett, D. F., and Pardee, J. T.: Manganese in western hydrothermal ore deposits. Ore deposits of the western States (Lindgren volume), A. I. M. E., pp. 676–678, 1933.

the west side of the Sevier Desert in Millard and Juab Counties (Fig. 2). The mountains are moderately rugged, though they rise only 2,500 feet above the plain of old Lake Bonneville to the east. Maximum altitudes are slightly over 7,000 feet. Many dry washes, some of them in narrow canyons, diverge from the crestline of the range, which has a northwesterly trend (Fig. 2).

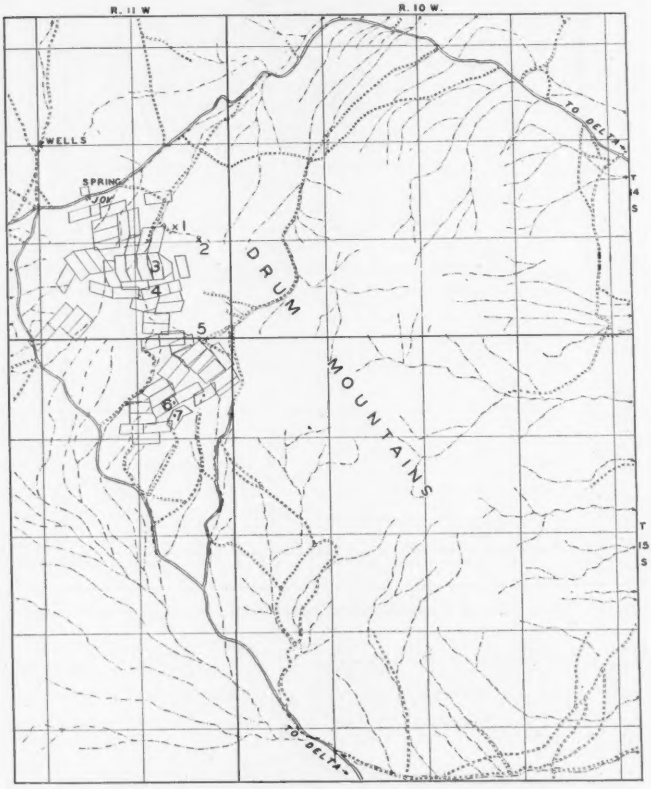

FIG. 2. Sketch map of the Drum Mountains and Detroit mining district. (1) Black Boy No. 6 and Spohr property, (2) Black Boy No. 5, (3) Ibex, (4) Keystone, (5) Utah Central, (6) E. P. H., and (7) Charmed.

Rock pediments underlain by volcanic rocks have been formed on the southwest side of the mountains. The region, typical of much of the Great Basin, is barren, has little rainfall, and little groundwater.[3] A developed spring at Joy (Fig. 2) and some wells northwest of Joy are the only local sources of water. Most of the drinking water is brought in from Delta.

The principal manganese deposits are in a ravine at the northwest side of the Drum Mountains near the south side of sec. 25, T. 14 S., R. 11 W., about 1 mile east-southeast of the abandoned town of Joy (1 and 2, Fig. 2). They are reached by road from Delta, which lies 37 miles to the southeast and is the nearest shipping point on the Union Pacific Railroad (Fig. 1). The altitude of the deposits is about 6,000 feet. The surrounding region, known as the Detroit mining district, has been extensively prospected for precious and base metals, and some of the claims noted in Fig. 2 have yielded a moderate production of these metals.[4] The noted mineral locality of Topaz Mountain[5] lies about 11 miles northwest of the manganese deposits.

GENERAL GEOLOGY.

The Drum Mountains essentially form an "island" of Cambrian sedimentary rocks which is surrounded on all sides but the east by Tertiary (?) volcanic rocks, chiefly of rhyolitic and latitic composition. The main road on the west side of the mountains (Fig. 2) follows the contact between sedimentary and volcanic rocks rather closely. On the east side, alluvial fans slope down from the mountains to the alluvial plain of the Sevier Desert. These fans are notched by shorelines of Lake Bonneville.[6]

Quartzite and interbedded sandy shale, which appear to be largely if not wholly of Lower and Middle Cambrian age, form the larger part of the Drum Mountains. The Prospect Mountain

[3] Meinzer, O. E.: Groundwater in Juab, Millard, and Iron Counties, Utah. U. S. Geol. Surv. Water-Supply Paper 277, p. 65, 1911. Butler, B. S.: Ore deposits of Utah. U. S. Geol. Surv. Prof. Paper 111, p. 458, 1920.

[4] Butler, B. S.: *Op. cit.*, pp. 463–465, 1920.

[5] Palache, Charles: Minerals from Topaz Mountain, Utah. Am. Mineral., vol. 19, pp. 14–15, 1934.

[6] Gilbert, G. K.: Lake Bonneville. U. S. Geol. Surv. Mono. 1, 1890.

quartzite, Cabin shale, and Busby quartzite of the Gold Hill district [7] may be represented. Overlying the quartzite there are beds of dolomite, limestone, and shale that in part may be the Abercrombie formation [8] of Middle Cambrian age. Fossils collected by Butler [9] from these rocks at several localities were determined to be of Middle and Upper Cambrian age. These beds are exposed in a band over a mile wide along the southwestern side of the mountains. The few samples of the carbonate rocks that were tested proved to be dolomite, and in many places, particularly near the Utah Central mine, the original carbonate beds, dolomite or limestone, have been recrystallized to gray dolomite over large areas. In places, silicates have been formed in these rocks. Neither the base of the quartzite beds nor the top of the carbonate beds is exposed. Butler [10] estimated the stratigraphic section to be 4,000 feet thick. Walcott [11] obtained a thickness of about 9,000 feet for the Cambrian section in the House Range, 15 miles to the southwest. The contact between the quartzite and dolomite is significant, for nearly all the manganese deposits or prospects are distributed along this contact.

Dikes of porphyritic latite or monzonite porphyry that lie in fractures in the sedimentary rocks have been exposed in mine workings, both in the manganese and in the precious metal deposits. A specimen from the Utah Central mine consists of a fine-grained groundmass composed chiefly of orthoclase and quartz with phenocrysts of quartz, andesine, hornblende, and biotite. These intrusive rocks commonly contain considerable pyrite, and weather to a clayey aggregate.

Structurally, the region is comparatively simple; the rocks form a homocline that dips southwest under the cover of volcanic rocks. The regional strike is about N. 35° W., and the dip about 25° SW. The Cambrian rocks are traversed by numerous faults,

[7] Nolan, T. B.: The Gold Hill mining district, Utah. U. S. Geol. Surv. Prof. Paper 177, pp. 4–7, 1935.

[8] Nolan, T. B.: *Op. cit.*, pp. 8–10, 1935.

[9] Butler, B. S.: *Op. cit.*, pp. 459–460, 1920.

[10] Butler, B. S.: *Op. cit.*, p. 459, 1920.

[11] Walcott, C. D.: Cambrian sections of the Cordilleran area. Smithsonian Misc. Coll., vol. 53, no. 5, p. 185, 1908.

many of which are roughly parallel to the direction of dip. Most of the manganese deposits are related to these faults, which are readily detected by the offsets of the quartzite-dolomite contact. Of interest are persistent reports of drumming noises attributed to very slight earthquake shocks. No recent fault scarps were seen, and the extensive pediments suggest that the region has not been tectonically active since early or middle Pleistocene time at the latest.

HISTORY AND PRODUCTION.

According to Heikes,[12] the Detroit district was organized in 1872, and probably most of the output of precious and base metals was made before 1900. Manganese deposits are not mentioned by Butler. Doubtless the outcrops had been prospected to a slight extent, but as they contained no precious or base metals, they attracted no attention. The first recorded shipments of manganese ore were made in 1924, and shipments were still being made in 1937. More than 85 per cent of the output recorded in the table below came from the Black Boy group of claims of Mr. Fred Staats, and consisted chiefly of manganese oxides, though rhodochrosite was prominent in some of the shipments.

MANGANESE ORE SHIPPED (LONG TONS)

Shipments of manganese ore, chiefly from the Black Jack and Black Boy properties, made by Harry S. Joseph (1924–1925) and Fred Staats (1928–1937). (Compiled from files of Bureau of Mines; published by permission of Mr. Staats.)

Year.	Ore Containing 10 to 35 Per Cent Manganese.	Ore Containing 35 Per Cent or More Manganese.	Total.
1924	37		37
1925	1,000		1,000
1928	286		286
1929	4,124	47	4,171
1930	8,654		8,654
1931	123		123
1935	190		190
1936	1,312	1,635	2,947
1937	1,375	30	1,405
	17,101	1,747	18,813

[12] Heikes, V. C., in Butler, B. S.: Ore deposits of Utah. U. S. Geol. Surv. Prof. Paper 111, p. 464, 1920.

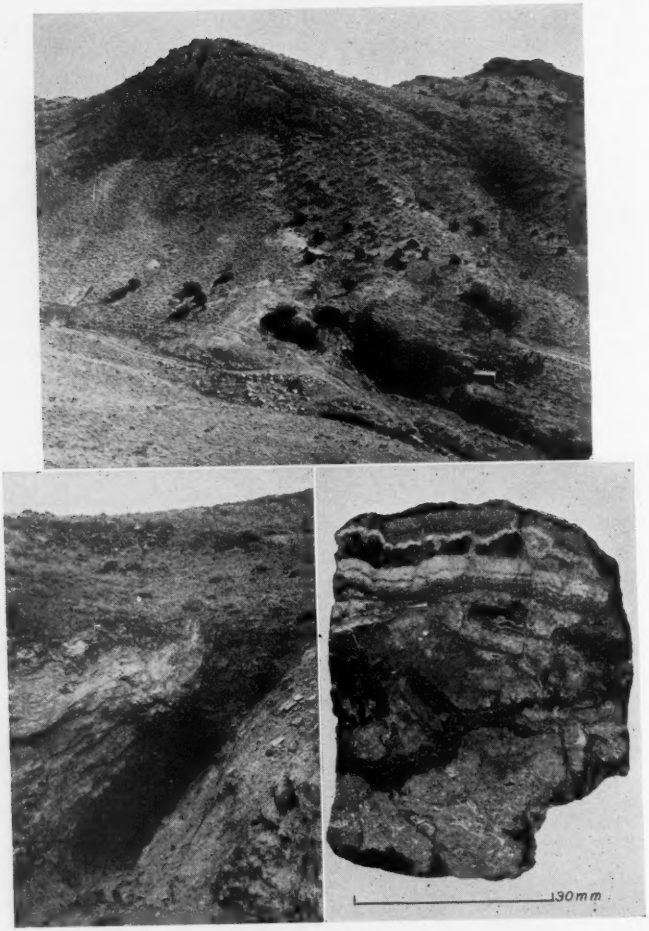

FIG. 3 (top). Open stopes, looking SE., at the Black Boy No. 5 manganese deposit. Southwestward-dipping Cambrian dolomite and shale beds outcrop above the mine. Fault, trending N. 75° E., extends along bottom of "draw," but is not exposed in the workings. Immediate foreground is underlain by quartzite, which lies on northern side of fault zone.

STRUCTURAL RELATIONS.

The Black Boy No. 5 deposit, from which most of the manganese ore has been obtained, lies in the bottom of a short ravine (Fig. 3). A fault, which probably has a curving course, follows the ravine in a general direction of N. 75° E., and offsets the quartzite-dolomite contact about 1,500 feet. The block south of the fault has been dropped, so that the ridge on the north side of the ravine is quartzite and interbedded shale, whereas the ridge on the south side is interbedded dolomite or limestone and shale. The bottom of the ravine is covered with rubble, which conceals most of the outcrops of the ore bodies. On the south side of the fault zone the regional strike of N. 35° W., dip 25°–33° SW., is maintained, but on the north side, the strike changes to north and the dip is 27° W. This sharp change in strike, as well as the indicated displacement, suggests that this is a persistent fault zone in which the rocks were sufficiently disturbed to provide channels for solutions and to facilitate replacement. Dikes of soft altered porphyritic latite have been revealed in the mine workings.

In the hangingwall of the fault zone there are three lenticular manganese ore bodies parallel to the bedding (Fig. 3). Each is stratigraphically higher toward the west, but, because of the southwestward dip, they lie at about the same altitude. The largest body had a pitch length of more than 100 feet, a width of about 70 feet, and a maximum thickness of about 25 feet. The other bodies were somewhat smaller. They pinched out at the bottom as well as at the ends, but no deep exploration has been undertaken to investigate the possibility of other shoots at greater depths. Pits and short tunnels along the course of the fault zone have revealed streaks of manganese oxides, but exploration has

FIG. 4. Stope in manganese oxides along fault zone on Spohr property (looking NE.) adjacent to Black Boy No. 6 claim, which lies to the left of the picture. Quartzite exposed at the right; shale and limestone beds at the left.

FIG. 5 (right). Rhodochrosite from Black Boy No. 5 mine. Banded veinlet of pink rhodochrosite at top; in center is typical gray rhodochrosite, here with pyrite. This specimen yielded material for analysis given below.

not been sufficient to disprove the presence of other minable bodies.

At the Black Boy No. 6 and Spohr properties another fault of northeasterly trend dipping 50° NW. brings dolomite and shale against quartzite (Fig. 4). The fault zone is mineralized, and small bodies of manganese oxides follow favorable beds in the hangingwall.

MINERALOGY.

Although the greater part of the mined ore was composed of manganese oxides, chiefly pyrolusite, the unweathered manganese carbonates found in the lower parts of some of the shoots have greater significance in revealing the nature of the deposits and their origin. Two distinct kinds of rhodochrosite are present. The more abundant variety is gray or black, fine-grained, and equigranular. It closely resembles the adjacent dolomite, and has doubtless been found by the replacement of dolomite. The second variety is a more typical pink, coarse-grained rhodochrosite that forms a network of vuggy veinlets (Figs. 5 and 6). The angular shapes of the blocks of gray rhodochrosite suggest brecciation before cementation by the pink rhodochrosite.

In the analyzed sample (Fig. 5), the gray rhodochrosite has an average grain size of about 0.03 millimeter. No variation in composition of the different carbonate grains that would indicate residue of the original carbonate could be detected. Although this sample contains very little, most samples of the gray carbonate contain scattered grains of quartz and flakes of muscovite, each as much as 0.15 millimeter long. At first thought these minerals might be considered as residual from the original country rock, but the fact that the quartz grains are commonly definite crystals, some with terminations, suggests that they are products of the mineralization. No rounded grains were seen Aggregates of sericite, some of them containing grains of barite, compose the small, white spots shown in Fig. 6. Pyrite in scattered anhedral grains is particularly abundant in the gray carbonate shown in Fig. 5, and even forms a narrow band in the pink rhodochrosite at the top of the specimen. The gray carbonate shown

in Fig. 6 contains only a few scattered grains of pyrite, although pyrite is clustered in some of the sericite aggregates.

The veinlets of pink rhodochrosite, which are mostly less than 10 millimeters wide, consist of crystals that commonly range between 0.2 and 1 milimeter in diameter. Vugs, such as are shown in Fig. 6, are lined with rhombohedral crystals, and curved

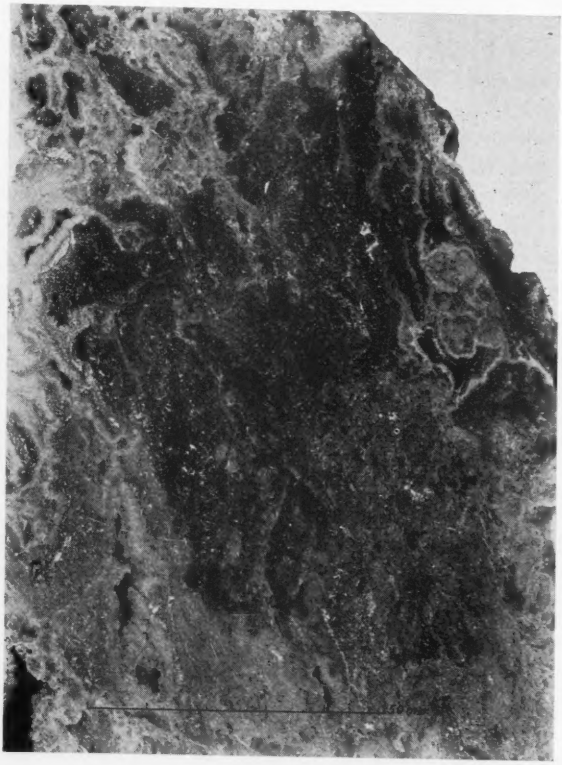

FIG. 6. Pink rhodochrosite (white or light-gray) and gray rhodochrosite (black) from Black Boy No. 5 mine. White spots represent chiefly sericite, some of which contains barite grains. Angular blocks of gray variety at top; vuggy veinlets of pink rhodochrosite throughout.

cleavage surfaces appear in some crystal groups. The banded pink rhodochrosite shown in Fig. 5 is composed of plumose aggregates of crystals. The difference in color between the milky pink and clear pink varieties seems to be due to radially arranged minute inclusions. A few grains of pyrite occur in the pink rhodochrosite, although most of it is restricted to the gray variety. A band of pyrite grains follows the banding in the upper part of Fig. 5. In the specimen shown in Fig. 6, little streaks of sericite with associated pyrite and barite lie just beneath a crust of pink rhodochrosite. Two grains of sphalerite less than 1 millimeter in diameter were found immediately under pink crystals in the specimen shown in Fig. 6. Groups of gypsum crystals have formed on the surfaces of rhodochrosite crystals in vugs.

At a few places, equigranular aggregates of fine-grained quartz, which contain sheafs of sericite and scattered crystals of barite, were found at the margins of the rhodochrosite ore shoots. The owner reports that the ore became more silicious toward the margins, so there is a suggestion that the shoots were enclosed in an envelope of silicious material. This quartz has an average grain size of 0.06 millimeter, but the barite crystals are as much as 1 millimeter long.

The analyses recorded below show the differences in composition between the early gray and the late pink varieties of rhodochrosite. The gray variety contains more insoluble impurities, chiefly pyrite, than the pink variety. In terms of the carbonates, the pink rhodochrosite contains more $MnCO_3$ and $FeCO_3$ than the gray variety, but less $CaCO_3$ and $MgCO_3$. So far as could be determined under the microscope, all the carbonate in both varieties is rhodochrosite. The refractive indices (ω) of the two rhodochrosites, so dissimilar in appearance and composition, were found by Miss Jewell J. Glass, of the Geological Survey, to differ by a maximum of only 0.005; that is, 1.817 for the gray rhodochrosite and 1.822 for the deepest pink rhodochrosite. Nearly white rhodochrosite on the surfaces of some vugs was found to have essentially the same index as the pink variety, and minute veinlets traversing both the pink and the gray rhodochrosite were

found to have the same index as the pink variety. Rhodochrosite with an index (ω) of 1.826 was cited by Larsen and Berman [13] as having a composition of 79.3 per cent $MnCO_3$, 19.9 per cent $FeCO_3$, 0.8 per cent $CaCO_3$. Rhodochrosite from the Conjecture mine, Lake Pend Oreille, Idaho, was found by Shannon [14] to contain 60.26 $MnCO_3$, 12.86 per cent $FeCO_3$, 11.06 per cent $CaCO_3$, and 15.48 per cent $MgCO_3$. The few analyses of rhodochrosites that have been made indicate highly variable proportions of the four carbonates that are usually determined. According to Mr. Staats, assays reveal no more than traces of the precious or base metals.

ANALYSES OF RHODOCHROSITES FROM THE BLACK BOY NO. 5 MINE, DRUM MOUNTAINS, UTAH.

R. K. Bailey, analyst.

	Gray.	Pink.
MnO	40.53	47.90
FeO	5.65	9.65
MgO	2.75	1.16
CaO	4.80	1.56
CO_2	35.35	38.16
Insoluble	9.28	.48
	98.36	98.91
$MnCO_3$	65.65	77.65
$FeCO_3$	9.11	15.57
$MgCO_3$	5.75	2.43
$CaCO_3$	8.57	2.78
Insoluble	9.28	.48
	98.36	98.91

ORIGIN.

The available data suggest that the rhodochrosite deposits are of hypogene origin, and that they have formed by replacement of favorable beds or fault breccias of Cambrian dolomite or limestone. The faults provided channels for the solutions, and the pronounced movement on the fault at the Black Boy No. 5 mine disturbed the adjoining beds to facilitate more than the usual in-

[13] Larsen, E. S., and Berman, Harry: The microscopic determination of the nonopaque minerals. U. S. Geol. Surv. Bull. 848, p. 229, 1934.

[14] Shannon, E. V.: Minerals of Idaho. U. S. Nat. Mus. Bull. 131, p. 236, 1926.

filtration of solutions and the replacement. The manganiferous solutions first replaced the fine-grained dolomite or limestone to form a fine-grained aggregate of gray rhodochrosite that retained the form and color of the original rock. These solutions also doubtless brought, in small amounts, the ingredients of quartz, sericite, muscovite, barite, pyrite, and sphalerite, all of which were probably formed during or closely following the first stage of manganese mineralization. Slightly later in the process, the gray rhodochrosite was brecciated, purer manganiferous solutions penetrated the breccia and cemented it with pink rhodochrosite that contained negligible quantities of impurities. It is not known whether these later solutions obtained their manganese content through leaching of the earlier gray rhodochrosite, or derived it from a deep-seated source. In any event, the later rhodochrosite differs both in composition and impurities from the early variety. The earlier rhodochrosite was replaced in places by the pink variety, and in some specimens tiny veinlets of rhodochrosite cross both the pink and the gray varieties. Weathering of the carbonates produced the oxides that formed the greater part of the ore removed.

The deposits in the Drum Mountains share with those at Philipsburg, Mont.,[15] and Batesville, Ark.,[16] the distinction of being one of the few examples of replacement of carbonate rocks by rhodochrosite. Hewett and Pardee [17] have pointed out that where manganiferous carbonates replace carbonate rocks, the product is generally manganosiderite, in which the iron greatly exceeds manganese. The reason for the preponderance of manganosiderite is not apparent; it is probably due largely to the original constitution of the solutions.

[15] Hewett, D. F., and Pardee, J. T.: Manganese in western hydrothermal ore deposits. Ore deposits of the western States (Lindgren volume). A. I. M. E., pp. 677–678, 1933.

[16] Miser, H. D., and Hewett, D. F.: The unweathered manganese deposits of the Batesville district, Ark. (abstract). Am. Mineral., vol. 23, no. 3, p. 175, 1938; also ECON. GEOL., vol. 32, no. 8, p. 1069, 1937.

[17] Hewett, D. F., and Pardee, J. T.: *Op. cit.*, p. 676, 1933.

ACKNOWLEDGMENTS.

Mr. D. F. Hewett of the Geological Survey directed this study and has read the manuscript critically. The writer is indebted to Messrs. R. H. Ridgway and H. W. Davis of the Bureau of Mines for the production table. He is especially indebted to Mr. Fred Staats, manger of the Black Boy property, and to Mr. Spohr for information and help in the field.

U. S. GEOLOGICAL SURVEY,
WASHINGTON, D. C.,
May 2, 1938.

THE DEPOSITION OF NATIVE COPPER UNDER HYDROTHERMAL CONDITIONS.

LINCOLN R. PAGE.

ABSTRACT.

In experiments, metallic copper was dissolved, in the absence of air and the presence of silica, by solutions of sodium chloride, carbonate and sulphate; calcium chloride; and carbon dioxide, at temperatures of 200° C. and 300° C. On cooling, native copper was deposited. In the presence of air, cuprite and native copper precipitated from sodium chloride solutions. Experiments with similar solutions, with datolite, prehnite and apophyllite, at room temperature yielded copper oxides and carbonates, but no native copper. Metallic silver was dissolved by sodium carbonate and calcium chloride solutions at 300° C. and 200° C. respectively and deposited as native silver.

Consideration of the experimental data, as well as mine water analyses and mineral paragenesis, suggest that the native copper of the Michigan and similar deposits formed at temperatures above 100° C., and probably above 200° C., by cooling of copper-bearing solutions rich in sodium, calcium and chloride, but relatively poor in iron and sulphide.

INTRODUCTION.

A NUMBER of experimental studies have been made in an attempt to clarify the method by which native copper has been formed in deposits of the Lake Superior type. A primary assumption in the majority of these studies has been that the formation of native copper is related to the oxidation or reduction of copper-bearing solutions by either ferric or ferrous compounds. Little experimental data have been obtained concerning the possible precipitation of native copper, at elevated temperatures, from solutions of sodium chloride, sodium carbonate, sodium sulphate, calcium chloride, and carbon dioxide in the absence of iron compounds. The results of experiments with such solutions suggest, as an alternate hypothesis for the origin of native copper in hypogene deposits, that cooling of chloride solutions is of more importance than the oxidation or reduction of solutions by iron.

ACKNOWLEDGMENTS.

It is a pleasure to acknowledge the many valuable suggestions and criticisms of Dr. J. W. Gruner, of the University of Minnesota, who suggested this problem, and under whom the majority of the experimental work was carried out. Dr. R. B. Ellestad, of the University of Minnesota Laboratory for Rock Analysis, rendered valuable assistance with the many chemical problems involved. The writer is also indebted to Dr. A. C. Lane, of Tufts College, and to Dr. H. M. Bannerman, of Dartmouth College, for their interest and criticisms during the progress of this work, and to Mr. John Emery Adams, of the Standard Oil Company of Texas, for his critical reading of the manuscript.

PREVIOUS EXPERIMENTAL WORK.

In 1871 Pumpelly [1] attributed the formation of native copper to the reaction of copper carbonate or sulphate solutions with ferrous compounds. Thirty years later Biddle [2] precipitated native copper, at ordinary temperatures, from solutions of ferrous and cupric chlorides in the presence of excess alkaline carbonate. Fernekes [3] obtained copper from similar solutions in the presence of prehnite and datolite at temperatures of 200°–250° C. Experimental work by Stokes [4] showed that copper was deposited, (1) by cooling hot solutions of cuprous and cupric sulphates, (2) by action of ferrous sulphate on cupric sulphate at 200° C., and (3) by the action of hornblende and siderite on cupric sulplate at 200° C. Sullivan [5] stated that cupric sulphate would react with silicates such as the feldspars, biotite, prehnite, augite, amphiboles, etc., causing the bases in the silicate molecule to be

[1] Pumpelly, R.: The paragenesis and derivation of copper and its associates on Lake Superior. Am. Jour. Sci., vol. 2, p. 352, 1871.

[2] Biddle, H. C.: The deposition of copper by solutions of ferrous salts. Jour. of Geol., vol. 9, pp. 430–436, 1901.

[3] Fernekes, G.: Precipitation of copper from chloride solutions of ferrous chloride. ECON. GEOL., vol. 2, p. 580, 1907.

[4] Stokes, H. N.: Experiments on solution, transportation and deposition of copper, silver and gold. ECON. GEOL., vol. 1, p. 644–650, 1906.

[5] Sullivan, E. C.: The interaction between minerals and water solutions. U. S. Geol. Surv. Bull. 312, p. 64, 1907.

removed and native copper to be deposited. Rassenfasse,[6] Castro,[7] and Nishio [8] produced colloidal copper from cupric sulphate solutions by means of organic reducing agents such as formaldehyde, acetylene, etc. Nishio also produced silver by the same method. As the result of an extensive experimental study, Wells [9] suggests four possible ways of depositing native copper, (1) cooling of cuprous sulphate solutions, (2) dilution of cuprous chloride, (3) oxidation of cuprous sulphide by solutions of ferric oxide in sulphuric acid, and (4) reduction of any oxidized copper compound by ferrous salts.

While working on the solution of silica in alkaline solutions at high temperature, J. W. Gruner noticed that copper dissolved from a copper bomb that he was using and was precipitated in the silica as minute crystals. This accidental discovery led to the experiments performed by the writer as well as those made by Park.[10] The latter obtained crystals of metallic copper by heating copper wire in solutions of magnesium carbonate with either sodium or potassium carbonate, a drop of water glass and solid carbon dioxide, at 300° C., for 185 to 210 hours. These experiments were made in a gold lined pressure bomb.

SUMMARY OF EXPERIMENTAL DATA BY THE WRITER.

1. Metallic copper was dissolved by solutions of sodium chloride, sodium carbonate, sodium sulphate, calcium chloride, and carbon dioxide, in the absence of air, at temperatures of 300° C. and 200° C., and under pressure equal to the vapor pressure of water, plus the partial pressure of other gases present, at these temperatures. It was likewise dissolved at 150° C. by sodium

[6] Rassenfasse, A.: Ueber eine neue Bildung von Kolloiden Kupfer. Chem. Zentralbl. I. S. 122, 1911.

[7] Castro, N.: Ueber die Darstellung Kolloiden Metals mit Hilfe von Adrolein. Zeitsch. für Chemie und Industrie der Kolloide, Band 6, p. 283, 1910.

[8] Nishio, K.: Native copper and silver in the Nonesuch Formation, Michigan. ECON. GEOL., vol. 14, pp. 324–334, 1925.

[9] Wells, R. C.: Chemistry of deposition of native copper from ascending solutions. U. S. Geol. Surv. Bull. 778, 1925.

[10] Park, C. F.: Hydrothermal experiments on copper minerals. ECON. GEOL., vol. 26, p. 879, 1931.

carbonate solutions. After cooling, this dissolved copper was present as crystals or irregular masses of the native metal.

2. Native silver was deposited under similar conditions from calcium chloride and sodium carbonate solutions.

3. In experiments at 300° C. with sodium chloride solutions and in the presence of a limited supply of oxygen, cuprite as well as native copper was formed.

4. In the presence of sodium ion, a yellow dehydrated copper hydroxide and a reddish-brown hydrated cupric oxide accompanied native copper experimentally precipitated. These compounds are unstable and would probably not exist in nature.

5. The relative ability of the salts studied to take native copper into solution at high temperatures and under pressure is as follows: calcium chloride (greatest), sodium chloride and sodium carbonate, sodium sulphate, and carbon dioxide.

6. Copper carbonates did not form above 150° C. in the absence of air, but appeared in experiments at room temperature.

7. At room temperature, and in the presence of limited amounts of air, calcium chloride, sodium chloride, and sodium carbonate solutions dissolved copper. Its solubility was greatest in the calcium chloride and almost nil in sodium carbonate solutions. The copper dissolved was partially deposited as carbonates and oxides.

8. Datolite increased the solubility of metallic copper in solutions of sodium chloride and calcium chloride at room temperatures. Calcite tended to decrease the solubility of copper in similar solutions.

9. Prehnite and apophyllite had no effect on the solution of copper in sodium carbonate solutions at room temperature.

GENERAL EXPERIMENTAL PROCEDURE.

Twenty hydrothermal experiments (Tables I, III, V, VII and VIII) were performed with copper, under the direction of J. W. Gruner, at the University of Minnesota in 1931, 1932, 1935 and 1936. Of these, five were of doubtful quantitative value and have been omitted from the tables. In addition, three similar experiments were made with silver.

All experiments were carried out in gold lined, steel pressure bombs of 50 c.c. capacity. Three yards of loosely coiled wire were used as the source of copper, except in experiment 17 (Table V) where sheet copper was used. Solutions were made by adding known weights of sodium chloride, sodium carbonate, sodium sulphate, calcium chloride, and solid carbon dioxide to 25 c.c. of distilled water. About 1 c.c. of silica gel, made by neutralizing water glass with hydrochloric acid, was added to act as a collecting agent for the copper crystals formed. The presence of silica was not essential to the reaction as can be seen by the results of experiment 2 (Table I) in which it was omitted. As the presence of oxygen caused the formation of cuprite (Expt. 4, Table I) the bombs were sealed in an atmosphere of nitrogen or carbon dioxide. Oxygen was removed from the distilled water by boiling. The amount of copper taken into solution was determined by weighing the copper wire at the beginning and at the end of the experiments. Small amounts of silica and the end products could not be completely removed from the wire in all cases, consequently the weights given in the tables represent a minimum figure for solution.

The bombs were heated in an electric muffle furnace in which the desired temperature remained constant during the period of the experiments. As designated in the tables, the experiments were maintained at the desired temperature for different lengths of time. Most experiments were of 137 to 145 hours duration, although one was heated for 65 hours, another for 205 hours. Upon cooling, the contents of the bomb were examined under a binocular microscope.

The pressure within the bomb was governed by the temperature. At any particular temperature it was equal to the vapor pressure of water, plus the partial pressure of other gases present, for that temperature. The presence of non-volatile salts and the solution of gases would alter the pressure slightly. The approximate pressure was 85 atmospheres at 300° C., 15 atmospheres at 200° C., and 5 atmospheres at 150° C., except in experiments with solid

carbon dioxide. The pressures with carbon dioxide were approximately 225 and 125 atmospheres at 300° C. and 200° C. respectively.

At the suggestion of A. C. Lane, ten experiments, at room temperature, were made (Tables II, IV, and VI) with solutions of sodium chloride, sodium carbonate, and calcium chloride, comparable in concentration with those of the hydrothermal experiments. Copper wire, in 10 c.c. of solution, was sealed in glass tubes of approximately 20 c.c. capacity. The tubes were sealed in air. In some experiments calcite, datolite, prehnite or apophyllite was added. The solutions of sodium chloride and calcium chloride were allowed to stand 1102 days and those with sodium carbonate 1407 days. After dissolving the end products in acid, the amount of copper taken into solution was determined by titration. Since it was not feasible to remove all the oxides from the copper wires the results represent a minimum of solution.

EXPERIMENTS WITH SODIUM CHLORIDE.

Experiments at 300° C. (Table I).—Sodium chloride solutions of two concentrations (approximately 0.5 and 1 normal) were made by adding 0.730 g. and 1.462 g. of sodium chloride to 25 c.c. portions of distilled water. As indicated by the amount of copper taken into solution in experiments 3 and 4, 0.248 g. and 0.241 g. respectively, the difference in the concentration of the solutions appears to be of little importance at this temperature. The apparently lower solubility noted in experiment 2 is probably caused by partially dehydrated copper hydroxide adhering to the wire at the end of the experiment, although it is barely possible that silica, which was omitted in this experiment, may have a slight tendency to increase the solubility of copper.

The majority of the dissolved copper was reprecipitated as a copper plate on the gold lining of the bomb, as copper crystals, wires, up to 3 mm. long, and irregular masses. In addition small amounts of yellow and reddish-brown basic salts were formed. These are probably the partially dehydrated copper hydroxide, $Cu_8O_3(OH)_2$, and the hydrated cupric oxide,

$Cu_2(OH)_2$, respectively. In experiment 4, air was present above the solution and small, euhedral crystals of cuprite and amorphous masses of the black oxide of copper were also formed. Copper crystals, wires and irregular masses as well as the basic salts were found inclosed in silica. The basic salts also encrusted the copper wire and the plate on the walls of the bomb. The solution at the close of the experiment was colorless and gave no test for copper.

TABLE I.

EXPERIMENTS ON THE SOLUBILITY OF COPPER IN SODIUM CHLORIDE SOLUTIONS AT ELEVATED TEMPERATURES.

No.	Grams of NaCl in 25 c.c. of Water.	Grams of Copper Wire Used.	Grams of Copper Dissolved.	Time in Hours.	Temp. (C°).	End Products.
1	0.0	1.934	0.0	144	300°	None.
2	0.730	1.961	0.215	137	300°	Copper plate on walls of bomb. Crystals and wires. Yellow and reddish-brown basic salts. No copper in the colorless solution.
3	0.730	3.139	0.248	137	300°	
4	1.462	2.915	0.241	145	300°	Same as exp. 2 and 3 plus cuprite and black oxide.*
5	1.462	3.206	0.055	137	200°	Same as exp. 2 and 3.
6	0.730	1.934	0.078	144	200°	Same as exp. 2 and 3.

* Air above solution.

TABLE II.

EXPERIMENTS ON THE SOLUBILITY OF COPPER IN SODIUM CHLORIDE SOLUTIONS AT ROOM TEMPERATURE.

No.	Grams of NaCl in 25 c.c. of Water.	Grams of Copper Wire Used.	Grams of Copper Dissolved.	Time in Days.	Minerals Present	End Products.
7	1.462	0.412	0.001 or less	1102	None	Green copper carbonate. Wire oxidized black.
8	1.462	0.370	0.062	1102	Dato-lite	Blue and green copper carbonates. Wire corroded.
9	1.462	0.388	0.001 or less	1102	Calcite	Green copper carbonate. Wire very bright.

The exact nature of the reaction which results in the solution and precipitation of the copper can not be definitely stated. The copper undoubtedly went into solution as a chloride, probably as cuprous chloride, since $Cu_8O_3(OH)_2$ forms by the decom-

position of cuprous chloride in the presence of soda and potash. The precipitation of copper from sodium chloride, as well as the other solutions tried, may have occurred in one of the following ways: (1) by the cooling of cuprous solutions, (2) by the breakdown of cuprous solutions at high temperature, (3) by a contact effect of copper in contact with the gold lining of the bomb.

The first possibility is favored because on cooling, a reversal of the reaction that took copper into solution would take place with sufficient rapidity to precipitate copper. Under these conditions precipitation must have started while the temperatures were still fairly high, for in experiments at 300° C. part of the copper on the walls of the bomb became alloyed with the gold to form an intermetallic compound, probably AuCu. Experiments 5 and 6, described below, show that this alloy is formed at temperatures above 200° C.

In addition, basic salts were noted coating the copper plate on the bomb indicating that the major portion of the copper precipitated as the metal first, probably while the temperature was still high, and that the basic salts formed later.

The second possibility is supported by Wells' experiments,[11] at 100° C., with cuprous chloride, ferrous chloride and sodium chloride, when the pH value was greater than 5.0 (regulated by sodium acetate and acetic acid) native copper and ferric oxide precipitated together from boiling solutions. Increasing the amount of sodium chloride seemed to facilitate precipitation. In this case precipitation was not dependent upon cooling, and although these experiments are of quite different nature from those under consideration, in that ferrous salts were absent, they do suggest that perhaps precipitation can take place at high temperature, and that cooling may not be the only factor involved.

The last possibility may be eliminated, for in experiment 6 the copper wire was placed in a silica glass tube which insulated it from the gold. The presence of the copper plate only on that part of the bomb which was in contact with the solution eliminates the possibility that copper was precipitated by vapors above the solutions.

[11] Wells, R. C.: *Op cit.*, p. 65.

Experiments at 200° C. (Table I).—Experiments at 200° C. showed a marked decrease in the amount of copper dissolved as compared with those at 300° C. With the exception of the formation of a copper gold alloy, the copper dissolved was precipitated in the same forms as in experiments described. The solution of copper in experiment 5 is actually more than that indicated in the table as the copper wire was heavily coated with basic salts, and in addition, a portion of the wire, which evidently remained above solution during the experiment, had a small amount of gold on it. The thin film of gold completely encircled the wire where it had been in contact with the wall of the bomb. This suggests that the gold may have been transported in the vapor above the solution.

Experiments at Room Temperature. (Table II).—In experiment 7, 10 c.c. of sodium chloride solution, containing 1.462 g. of sodium chloride in 25 c.c. of water, and a copper wire were sealed in a glass tube with air above the solution. This experiment is comparable to experiment 4 (Table I), although no gold was present. Since reaction time increases with a decrease in temperature, the time element was increased to 1102 days. Within a few days the solution acquired a green tint, and the wire became coated with a black oxide. A green precipitate, probably copper carbonate, formed on the walls and bottom of the tube. No appreciable change occurred after the first few weeks, except that the products noted above became slightly more abundant. Careful examination under the microscope failed to reveal the presence of native copper. Henstock [12] and Crowe [13] have shown that metallic copper is dissolved by boiling solutions of sodium chloride, and either remains in solution or forms a green precipitate. This would indicate that precipitation of native copper from sodium chloride solutions takes place only above 100° C. Tests with ammonia showed that 0.001 g. or less of copper was dissolved during experiment 7.

[12] Henstock, H.: Action of natural waters on metallic copper. Jour. Soc. Chem. Ind., vol. 44, p. 219, 1915.

[13] Crowe, C. H.: The action of several salt solutions on aluminium, copper, lead and zinc. Can. Chem. Met., vol. 6, pp. 151–152, 1922.

Similar experiments with sodium chloride, in the presence of calcite and datolite, indicated that native copper is not formed at ordinary temperatures by the neutralizing effect of these minerals. However, experiments 8 and 9 show that, in their presence, copper was dissolved and precipitated either as carbonates or as oxides. In the presence of calcite, copper was deposited as a green carbonate. The copper wire remained unoxidized. Comparison of the end products with those of experiment 7 suggests that calcite retards solution very slightly. In the presence of datolite 0.062 g. of copper dissolved and precipitated both as the blue and green carbonates. The wire was coated with black copper oxide.

EXPERIMENTS WITH CALCIUM CHLORIDE.

Experiments at 300° and 200° C. (Table III).—Solutions containing approximately 1.820 g. of calcium chloride (weighed as $CaCl_2 \cdot 2H_2O$) per 25 c.c. water were found to be the most active copper solvents of all reagents tried at 300° C. The 0.304 g. of copper dissolved was precipitated as crystals, wires, dendrites, and as a plate on the lining of the bomb. The longest wire noted was .3 mm. No basic salts formed.

TABLE III.

EXPERIMENTS ON THE SOLUBILITY OF COPPER IN CALCIUM CHLORIDE SOLUTIONS AT ELEVATED TEMPERATURES.

No.	Grams of $CaCl_2$ in 25 c.c. of Water.	Grams of Copper Wire Used.	Grams of Copper Dissolved.	Time in Hours.	Temp. (C°).	End Products.
10	1.820	3.194	0.304	134	300°	Copper plate on walls of bomb, crystals, wires. No basic salts. Solution colorless.
11	1.820	3.157	0.040	142	200°	Same as exp. 10.

At 200° C. the solubility of copper showed a marked decrease as in the case of sodium chloride.

As native silver is contemporaneously deposited with native copper in the Michigan deposits, an explanation for the origin of one should likewise explain the other. Consequently an experiment was made at 200° C. in which a sheet of silver was substi-

tuted for copper wire. At the end of 144 hours, 0.1208 g. of silver were dissolved. This was deposited as minute metallic crystals and as a plate on the walls of the bomb. Tests with sodium sulphide showed that some silver remained in solution at the end of the experiment. This experiment indicates that both native silver and native copper can be precipitated in the same manner from calcium chloride solutions.

TABLE IV.

EXPERIMENTS ON THE SOLUBILITY OF COPPER IN CALCIUM CHLORIDE SOLUTIONS AT ROOM TEMPERATURE.

No.	Grams of $CaCl_2$ in 25 c.c. of Water.	Grams of Copper Wire Used.	Grams of Copper Dissolved.	Time in Days.	Mineral Present.	End Products.
12	1.820	0.359	0.0016	1102	None	Green copper carbonate; reddish oxide on wire; solution colorless.
13	1.820	0.391	0.011	1102	Datolite	Green and blue copper carbonates; reddish and black oxides on wire; solution colorless.
14	1.820	0.360	0.001 or less	1102	Calcite	Green copper carbonate; wire bright; solution colorless.

Experiments at Room Temperature (Table IV).—Three experiments with calcium chloride solutions at room temperature, similar to those performed with sodium chloride, indicate that: (1) as noted in experiments at 300° C. copper is more soluble in calcium chloride than in sodium chloride solutions, (2) datolite favors the solution of copper while calcite tends to retard it, (3) copper is deposited as the carbonate and oxide, not as native copper.

EXPERIMENTS WITH SODIUM CARBONATE.

Experiments at 300° C., 200° C., 150° C. (Table V).—Three experiments with sodium carbonate solutions, made by adding 2.650 g. of this salt to 25 c.c. of water, show that the solubility of copper at 300° C. and 200° C. is about the same in sodium carbonate as in sodium chloride. In experiment 17 a temperature of 150° C. was used, and the duration of the experiment was de-

creased to 65 hours, about one half that of the other experiments. Even under these conditions, solution and precipitation took place. The small amount of copper dissolved was deposited as minute wires. Although at 300° C. and 200° C. the main portion of copper was precipitated in the native state, considerable amounts of yellow and reddish-brown basic salts were formed, indicating that these compounds form from sodium carbonate as well as sodium chloride solutions. Very little, if any, copper remained in solution after cooling as indicated by negative NaI and Fe tests.

One experiment was made with sodium carbonate and silver at 300° C. Silver was deposited as crystals. Chloride tests for silver in the solution at the end of the experiment were negative, but tests with sodium sulphide were positive. This experiment indicates that silver as well as copper can be carried as a carbonate at these temperatures. It is probable that cooling is the chief factor of precipitation.

TABLE V.

EXPERIMENTS ON THE SOLUBILITY OF COPPER IN SODIUM CARBONATE SOLUTIONS AT ELEVATED TEMPERATURES.

No.	Grams of Na_2CO_3 in 25 c.c. of Water.	Grams of Copper Wire Used.	Grams of Copper Dissolved.	Time in Hours.	Temp. (C°).	End Products.
15	2.650	3.229	0.247	144	300°	Copper as plate on wall of bomb, crystals, wires. Basic salts, yellow and reddish-brown varieties. No copper in solution.
16	2.650	3.180	0.031	120	200°	Same as exp. 15.
17	2.650	0.688	0.007	65	150°	Copper as wires.

TABLE VI.

EXPERIMENTS ON THE SOLUBILITY OF COPPER IN SODIUM CARBONATE SOLUTIONS AT ROOM TEMPERATURE.

No.	Grams of Na_2CO_3 in 25 c.c. of Water.	Grams of Copper Dissolved.*	Time in Days.	Mineral Present.	End Products.
18	2.650	None by NH_3 test	1407	None	Wire dull, slightly oxidized.
19	2.650	None by NH_3 test	1407	Prehnite	Wire dull, slightly oxidized.
20	2.650	None by NH_3 test	1407	Apophyllite	Wire has dark oxide coating.

* Copper wire used in each experiment.

Experiments at Room Temperature (Table VI).—Three experiments were made at room temperature as in the case of sodium chloride and calcium chloride. Prehnite and apophyllite were used in place of calcite and datolite in experiments 19 and 20. Ammonia tests showed no copper in the solutions or in the sediment at the end of 1407 days. The copper wire was slightly oxidized. About two weeks after these experiments were started, the solution turned pale blue, but after one year it cleared, and no other visible change was noted. Probably the copper taken into solution was reprecipitated as the oxide on the wire.

EXPERIMENTS WITH CARBON DIOXIDE.

Experiments at 300° C. and 200° C. (Table VII).—Two experiments were made with solid carbon dioxide. Three to four grams of solid carbon dioxide were suspended above the solution on a platinum disc and the bomb sealed in an atmosphere of carbon dioxide. As in previous experiments, solution of copper was greatest at 300° C., but the amount dissolved was small compared with that in sodium chloride, calcium chloride, and sodium carbonate solutions. The copper was precipitated as wires, up to .25 mm. long, and as crystals. In experiment 21 no plate was formed on the bomb, but a thin one was noted in experiment 22.

TABLE VII.

EXPERIMENTS ON THE SOLUBILITY OF COPPER IN CARBON DIOXIDE SOLUTIONS AT ELEVATED TEMPERATURES.

No.	Grams of CO_2 in 25 c.c. of Water.	Grams of Copper Wire Used.	Grams of Copper Dissolved.	Time in Hours.	Temp. (C°).	End Products.
21	3.0–4.0	3.201	0.061	205	300°	Copper as crystals, wires.
22	3.0–4.0	3.181	0.042	137	200°	Copper as plate on walls of bomb, crystals, wires.

EXPERIMENTS WITH SODIUM SULPHATE.

Experiments at 300° and 200° C. (Table VIII).—Experiments made with sodium sulphate show that this salt is less effective in the solution and precipitation of copper than sodium

chloride, calcium chloride or sodium carbonate. The copper precipitated as native metal in the form of wires, crystals, dendrites, and a copper plate. At 300° C. considerable copper-gold alloy formed.

The copper in this experiment evidently went into solution as sulphate and was completely precipitated as the native metal. The cooling of cuprous sulphate is known to precipitate copper, and it is not surprising to find that this experiment should yield metallic copper. These results with sodium sulphate substantiate the cooling hypotheses suggested to explain the precipitation of copper from sodium chloride and other solutions.

TABLE VIII.

EXPERIMENTS ON THE SOLUBILITY OF COPPER IN SODIUM SULPHATE SOLUTIONS AT ELEVATED TEMPERATURES.

No.	Grams of Na_2SO_4 in 25 c.c. of Water.	Grams of Copper Wire Used.	Grams of Copper Dissolved.	Time in Hours.	Temp. (C°).	End Products.
23	3.559	2.990	0.153	144	300°	Copper plate on the walls of the bomb. Crystals and wires. Solution colorless.
24	3.549	3.117	0.017	144	200°	Same as exp. 23.

DISCUSSION.

The experimental data presented strongly suggest that: (1) native copper and silver of the Michigan type may have been deposited from chloride, carbonate, and perhaps sulphate solutions by cooling rather than chemical reactions, (2) the temperature of formation was above 100° C., and very probably above 150 C., (3) the present deep mine waters could be residues of the ore-bearing solutions.

Before considering these facts in detail, it is perhaps best to briefly review the hypotheses of previous workers on the Michigan and similar deposits. These hypotheses may be divided into the following groups based on:

(1) The reduction of oxidized copper solutions by ferrous compounds, either as minerals or solutions. This hypothesis has

been advocated by Pumpelly,[14] Smyth,[15] Van Hise and Leith.[16] It has been strengthened by the experimental work, previously cited, of Biddle, Fernekes and Stokes. Lane[17] believes that reduction is caused not only by the wall rock itself (iron-rich traps) but also by the hydrocarbons present.

(2) The oxidation of copper sulphide solutions by ferric compounds. Butler and Burbank, et al.[18] believe that ferric oxide acted as the oxidizing agent. This hypothesis is based upon the experimental work of Wells.[19] Watson[20] and Bastin[21] suggest that ferric silicates, especially epidote, cause the precipitation of native copper.

(3) The cooling of cuprous sulphate solutions. This has been demonstrated by Stokes[22] and Wells[23] and is advocated by Nishio[24] as the dominant process in the Michigan deposits.

(4) The dilution of cuprous chloride solutions. This has been experimentally demonstrated by Wells[25] was a method of precipitating copper.

Of these hypotheses it is probably safe to eliminate those dependent on special conditions such as presence of hydrocarbons

[14] Pumpelly, R.: The paragenesis and derivation of copper and its associates on Lake Superior. Am. Jour. Sci., vol. 2, p. 352, 1871.

[15] Smyth, H. L.: On the origin of copper deposits of Keweenaw Point. (Abstract) Science, New Ser., vol. 3, pp. 251–252, 1896.

[16] Van Hise, C. R., and Leith, C. K.: The geology of the Lake Superior region. U. S. Geol. Surv., Mon. 52, pp. 580–591, 1911.

[17] Lane, A. C.: Differentiation in traps and ore deposition. Econ. Geol., vol. 30, pp. 924–927, 1935.

[18] Butler, B. S., and Burbank, W. S., et al.: The copper deposits of Michigan. U. S. Geol. Prof. Paper 144, pp. 138–139, 1929.

[19] Wells, R. C.: Chemistry of deposition of native copper from ascending solutions. U. S. Geol. Surv., Bull. 778, pp. 40–41, 1925.

[20] Watson, T. L.: Native copper deposits of the South Atlantic States compared with those of Michigan. Econ. Geol., vol. 17, p. 746, 1923.

[21] Bastin, E. S.: The chalcocite and native copper types of ore deposits. Econ. Geol., vol. 28, pp. 429–437, 1933.

[22] Stokes, H. N.: *Op. cit.*, p. 644.

[23] Wells, R. C.: *Op. cit.*, p. 39.

[24] Nishio, K.: Genesis of the native copper and silver ore deposits in the Lake Superior region, U. S. A. World Engineering Congress, Paper No. 738, p. 22, Tokyo, 1929.

[25] Wells, R. C.: *Op. cit.*, p. 39.

and dilution of cuprous chloride solutions as being of minor importance, if active at all. It is questionable whether the first hypothesis is of major importance since one of the by-products would be ferric iron, and ferric-minerals later than the copper are not present in sufficient quantities to warrant acceptance of this hypothesis. The oxidation hypothesis is supported by much experimental and field evidence. Arguments favoring this theory for the Michigan deposits include: (1) the general sulphide character of mineralizing solutions in other areas, (2) the presence of the Duluth gabbro as a possible source of sulphide solutions, (3) the presence of large amounts of ferric oxide in the country rock which, as has been shown experimentally, could reduce the copper sulphide solutions, (4) the association of copper and bleached areas. However, the oxidation of copper sulphides by ferric oxide, in itself, will not yield native copper and subsequent cooling of the cuprous sulphate solutions formed is necessary for precipitation. Thus, even in the most plausible of previous theories, cooling is the most important factor in the deposition of native copper.

In the absence of experimental data on cooling of chloride solutions and the resulting precipitation of copper, the older theories of deposition from chloride solutions have been relegated to the background in favor of deposition from sulphide solutions. Arguments for the present hypothesis of deposition from chloride solutions are based upon: (1) the unusual amounts of sodium, calcium, and chloride in the deep mine waters at Keweenaw Point, and (2) the rarity of sulphide minerals noted there, (3) the association of copper with zeolites, and (4) the absence of appreciable amounts of late iron-bearing minerals.

The unusual amounts of sodium, calcium, and chloride ion in the deep mine waters of the Michigan mines has caused a number of writers to consider that they are residues of the ore depositing solutions. In the past one objection to this idea was the absence of experimental evidence to indicate that native copper can be precipitated from solutions of similar concentration without enlisting the aid of ferrous minerals. The sodium chloride

and calcium chloride solutions used in these experiments contained respectively 58.5 g., 29.8 g. (sodium chloride) and 54.8 g. (calcium chloride) per liter which compares favorably with amounts of calcium chloride and sodium chloride shown in an analysis of mine waters from the fifty-third level of the Quincy Mine, as given by Lane.[26] This analysis shows that 99 per cent. of all solids are:

Cl	176.027	g. per liter
Ca	86.478	g. per liter
Na	15.188	g. per liter

Assuming all Na and Ca are present as chlorides, calculation shows the concentration to be:

NaCl	37.68	g. per liter
$CaCl_2$	240.2	g. per liter

Thus, the sodium chloride concentration in these mine waters is between the extremes used in the experiments, whereas the natural calcium chloride concentration is more than four times that of the solution used. Experimental data show that the concentration of sodium chloride has little effect upon the amount of copper precipitated, at 200° C. and at 300° C., and this is probably also true for calcium chloride. Therefore, although the concentrations used in the experiments are not the same as that in the deep mine waters, it is evident that chemically these mine waters could have served as the ore solutions which deposited copper.

The rarity of sulphide minerals in these deposits is in itself a suggestion that the original solutions were low in sulphur, and this is also suggested by the extremely low concentration of sulphate in the deep mine waters. This is in keeping with the hypothesis of deposition by cooling from chloride solutions. The increased amounts of sulphides in unbleached areas over the bleached areas of the Michigan deposits is given as an argument

[26] Lane, A. C.: Mine waters. Paper read at the Thirteenth Annual Meeting of the Lake Superior Mining Institute. June 1908, p. 48.

for sulphide solutions. It certainly shows presence of sulphides and that, in all probability, some oxidation to native copper has taken place, but it does not prove that there was ever any great amount of sulphur in the ore depositing solutions. Probably some of these sulphides were originally present in the unaltered flow rock. Conditions were favorable in some unbleached areas for the precipitation of sulphides and arsenides as shown by their presence in the fissure type of deposits, but compared to native copper the percentage of these minerals is low. More should be present in favorable places if they were precipitating from sulphide solutions similar to those of other regions. Butler and Burbank [27] show that sulphur is more prominent in the two lowest lodes, the Baltic and Isle Royale, and less prominent in the higher ones. However, even here the main mineral is native copper. If the solutions were rich in sulphides and conditions were favorable for deposition, as they seem to have been, certainly one should expect an abundance of sulphide minerals to form in these lodes. Park [28] states that cuprous sulphide and cupric sulphide are formed from solutions of cuprous chloride, cupric chloride and cupric sulphate in the presence of steam and hydrogen sulphide at temperatures up to 500° C. These sulphides are stable as long as the hydrogen sulphide is present in excess of the amounts required to maintain equilibrium between the solid and the gas. The amount required would depend on the temperature and pressure of the system under consideration. A consideration of this statement suggests that possibly hydrogen sulphide was originally rare in these mineralizing solutions and therefore insufficient for the formation and preservation of sulphides except in minute amounts.

It is questionable whether the Duluth gabbro could act as a source of the sulphide solutions postulated, both on the basis of distance from the gabbro and because gabbro magmas are considered to be rather lean in mineralizers. In addition, those sulphides present usually precipitate in the gabbro itself as segrega-

[27] Butler, B. S., and Burbank, W. S.: *Op. cit.*, p. 132.

[28] Park, C. F.: Hydrothermal experiments with copper compounds. ECON. GEOL., vol. 26, p. 861, 1931.

tions, or very near by. The fact that this type of native copper deposit is unique suggests that quite possibly the ore-depositing solutions were not of the usual sulphide character, but of less normal nature, perhaps a chloride. Presence of chloride around areas of volcanic activity is not uncommon.

The association of native copper with bleached areas in the amygdaloids and conglomerates of the Michigan deposits, has been advanced to support the oxidation hypothesis. However, this association can be equally well explained by removal of iron by acid chloride solutions. Regardless of type, the solutions removing the iron would be rich in this element, which must have been removed in solution or used to oxidize sulphide solutions and form secondary iron-rich minerals, either within the ore deposit or elsewhere. The paragenesis of ore minerals as noted from personal observation of thin sections and as given by Butler and Burbank [29] indicates that the period of formation of secondary iron-rich minerals, such as prehnite, epidote and chlorite, was, for the most part, completed by the time copper began to deposit, and only small amounts of chlorite and ankerite formed later. As iron carbonate is less soluble than calcium carbonate, is it not surprising that copper is associated with calcite and zeolites rather than siderite, if it is assumed that considerable iron was in solution at the time copper was deposited? And is it not equally odd to find that those sulphides present are slightly later than the main portion of copper, if the solutions causing the bleaching were originally rich in sulphide? Explanation of higher sulphide content in the Baltic and Isle Royale lodes is based on the fact that the sulphide solutions lacked sufficient time to oxidize, and therefore more sulphide could deposit in these low lodes.

It would appear from these considerations that at the time copper was deposited, iron and sulphur compounds were rather limited in quantity and sodium and calcium plentiful. Bleaching evidently took place before deposition of copper. The association of copper and bleached areas may therefore be considered to be

[29] Butler, B. S., and Burbank, W. S.: *Op. cit.*, p. 54.

in one sense accidental, the copper depositing in the more permeable areas, which were naturally the same areas previously traversed by the bleaching solution.

The temperature at which these deposits formed is indicated by experimental data to be above 100° C. for experiments at room temperature, and at 100° C.[30] indicate that metallic copper is not deposited from sodium chloride and probably not from calcium chloride solutions below this temperature. An initial temperature below 200° C. would probably not be sufficient to accomplish the necessary transportation and deposition. Judging from experimental data, a temperature of 300° C. or higher would be more favorable. Probably the earlier hotter solutions caused the bleaching, and copper was deposited by later solutions at about 200° C.–300° C. As deposition is dependent on cooling and not upon chemical reactions, most of the copper would be expected to form in existing open spaces, such as in a conglomerate or amygdaloid.

To summarize, the deposition of native copper and associated silver, by cooling of chloride solutions, above 100° C., has been shown by experimental evidence to be a possible mode of origin for deposits such as those at Keweenaw Point, Michigan. Consideration of mineral paragenesis and analyses of deep mine waters substantiate this theory. Association of copper and bleached areas in the conglomerate and amygdaloidal country rocks is consistant with this hypothesis. The absence of appreciable amounts of sulphide minerals and the presence of carbonates and zeolites substantiate rather than invalidate this view.

MIDLAND, TEXAS,
May 1, 1938.

[30] Henstock, H.: *Op. cit.*, p. 219. Crowe, C. H.: *Op. cit.*, pp. 151–152.

A POLISHING APPARATUS FOR ORE MINERALS.

JOSEPH MURDOCH.

SUMMARY.

A description of convenient and improved apparatus for mounting specimens in bakelite, and for polishing them by Vanderwilt's method.

In the geological laboratory of the University of California at Los Angeles, the writer has developed a satisfactory system for the preparation and polishing of ore specimens for microscopic study. This system is based on that of Vanderwilt,[1] in which the grinding is very slow, using fine abrasives, and metal-surfaced laps. The working out of apparatus and method has been made possible by grants from the Research Fund of the University of California, and the writer wishes to express his appreciation of this aid. He also desires to acknowledge the valuable assistance of Mr. T. A. Watson, of the Department of Mechanic Arts, in the designing and machining of the apparatus. A general view of the polishing machine is shown in Fig. 1, with a closer view of the head and lap in Fig. 2.

The principal aim of the investigation has been to devise a convenient, reasonably inexpensive apparatus which would produce results comparable to those of Vanderwilt's machine. This has been successfully attained, although the cost could not be brought as low as was desired, and it seems likely that this type of polishing will always require rather complicated apparatus. It is somewhat difficult to set an exact figure on the cost of duplicating the machine as it stands, because it arrived at its present form by a series of improvements, worked out by trial and error. However, a fair estimate might be between $200 and $250, including bakelite press and mould.

[1] Vanderwilt, J. W.: Some improvements in the polishing of ores. Econ. Geol., vol. 23, pp. 292–316, 1928.

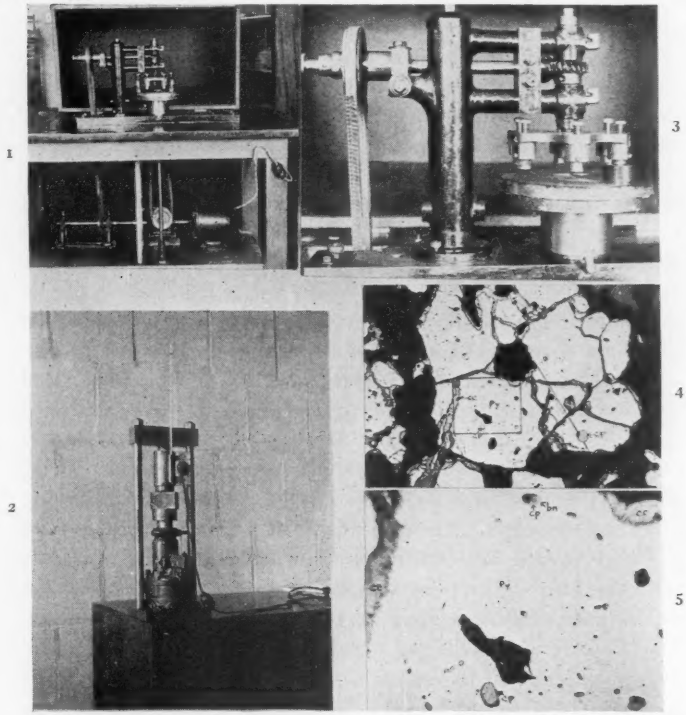

FIG. 1. General view of the polishing apparatus. The box at the back of the table is a dust-proof cover for use when the machine is not running.

FIG. 2. Close-up of head and lap.

FIG. 3. Bakelite press, with mould in place, ready to apply pressure. The block beneath the base of the mould is unnecessary, but is convenient for reducing the distance that the jack has to be pumped, while still allowing sufficient working distance to slip the mould into position on the plunger.

FIGS. 4 AND 5. Microphotographs of a specimen polished by this method. Magnifications are × 50 in 4, and × 200 in 5. The section shows pyrite grains, with blebs of chalcopyrite (and bornite), in a matrix of sooty chalcocite. Note the slight amount of relief between pyrite, hardness 6, and sooty chalcocite, hardness 1–2. Black patches are holes formerly filled with powdery "limonite." *G* = gangue. *cp* = chalcopyrite. *cc* = sooty chalcocite. *bn* = bornite. *py* = pyrite.

MOUNTING.

Since this method of polishing requires slow grinding, with fine abrasives, mechanical operation is necessary, so that a number of specimens may be handled at the same time, thus reducing the total time for each specimen. Mechanical operation in turn requires uniform mounting of specimens, and the writer has employed bakelite as a permanent mounting medium. Methods of mounting in bakelite have been described,[2] but each different type of equipment requires variation in the detail of technique.

The mounting apparatus used by the writer is a modification of that used at the California Institute of Technology. One specimen at a time is mounted, and when working steadily, six or seven specimens an hour may be prepared. The specimen, sawed or ground to a flat surface of appropriate size, is mounted in a circular block of bakelite in the following manner. A cylindrical sleeve of chrome steel with inside diameter of 1½ in., length of 4 in., and walls ⅜ in. thick, is enveloped in a brass jacket carrying a heating element. This element is made of 100 in. of No. 26 Chromel A wire, wound around the cylinder, properly insulated, and connected with an ordinary lighting plug socket. A socket to hold a thermometer, is clamped on the outside of the jacket. The sleeve rests on a flanged steel base, machined smooth and flat to form the face of the mount. A carefully fitted steel plunger, with about .001 in. clearance, 3⅛ in. long, is used to compress the bakelite. Both should be machined and polished so that they will slide readily. The plunger has a threaded hole in the top, so that it may be solidly anchored to the top bar of the press frame. It has a narrow groove, from top to bottom, to allow the escape of air from the mould. On the bottom, it is machined to a flat face with a projecting knob centered on it, to form a hemi-

[2] Head, R. E., and Slavin: Technical paper, no. 10, Univ. of Utah, 1930.

Krieger, P., and Bird, P. H.: Mounting polished surfaces in bakelite. ECON. GEOL., vol. 27, pp. 675–678, 1932.

Fuller, H. C.: Mounting polished surfaces in bakelite. ECON. GEOL., vol. 28, pp. 393–395, 1933.

Stillwell, F. L.: Bakelite press for mounting mineral grains and ores. Australasian Instit. of Mining and Metallurgy, Proc. N. S. no. 90, p. 237, 1933.

spherical depression in the top of the bakelite. This depression is made to hold a 5/16 in. ball, and is 1/32 in. shallower than a full hemisphere. There is a similar depression in the specimen-holder on the machine head, so that the connection between specimen and machine is a ball-bearing universal joint. The requisite pressure is applied by means of a hydraulic jack [3] set in a frame (Fig. 3).

The mounts will then be uniformly 1½ in. in diameter, and approximately ¾ in. in thickness. The thickness may be kept constant by the use of a measuring cup for the bakelite, which should be 1⅝ in. in diameter and 1¼ in. deep. By measuring specimen and bakelite together in this way, the only variation in ultimate volume will be due to variation in the size of the specimen, which may be allowed for by using less or more bakelite, as necessary. If desired, a bakelite cup may be moulded, by using a tapered block of polished brass instead of the specimen. This block is then pulled out of the bakelite, and the specimen mounted in sealing wax in the cup. The writer has found that this is not usually necessary, as at the temperatures employed, few or none of the minerals involved are appreciably affected by the heat. Stillwell's press is somewhat more elaborate than the writer's. He uses two heating elements—one above and one below the mould, with also a substitute base for moulding bakelite cups. The temperatures employed are somewhat higher (at least from his thermometer readings) than the writer's, and his time of curing somewhat shorter, but his general procedure is essentially similar.

With this set-up the writer has adhered rather closely to the following procedure. Starting with a cold mould, it is necessary to pre-heat, because of the considerable temperature lag in the mass of metal. Accordingly, the sleeve, plunger, and base are assembled on a heat-insulating surface, the current is turned on, and run till the thermometer in the outside casing reads 160° C. The current is now turned off and left till the thermometer reading is 130° C., then on again to 140° C. By this time the heat is uniformly diffused through all parts of the mould. The plunger

[3] Made by the Walker Manufacturing Co., Racine Wisc.: no. 835, of 7 ton capacity, and with an automatic by-pass at the maximum pressure.

is removed, and attached by a screw bolt to the top of the press frame. The plunger, base, and inside of the sleeve, are lubricated with a thin film of mineral oil, to prevent sticking. The specimen is then placed, face down, in the center of the base, the sleeve set on, and the measured bakelite powder poured in. The assembled base and sleeve are now slid up over the plunger until the latter just touches the bakelite, and the jack pumped up enough to hold them in this position. The temperature is raised to 135–140° C., pressure applied slowly, up to the limit of the jack, and held there for eight minutes. The maximum pressure, about 4400 lbs. per square inch with this jack and this plunger area, is considerably more than necessary, but does no harm, and insures sufficient pressure without resorting to a gauge. The temperature will rise to 150–160° C., without further current, and may be allowed to drop to 133° C. After raising again to 137° C., the current is disconnected, and as a rule there will be enough heat in the system to finish the operation. It might be advisible, however, to check the temperature on the first specimen, and not allow it to drop below 120° C. It is necessary to insulate the mould from the press, at top and bottom, otherwise heat conduction will be so great that the bakelite will be soft and doughy, instead of being properly cured. For each insulator, a ¼ in. bakelite disc is ample. At the end of eight minutes, pressure is released, the sleeve backed off the plunger, and the specimen driven out by tapping with a wooden plunger. If the procedure is repeated at once with another specimen, the pre-heating may be omitted.

The finished specimen may be marked, preferably while still hot, with steel dies, for permanent identification. Machine cut dies are too dull, and shatter the bakelite, so that hand cut dies must be used. These mounts are so nearly parallel on back and face, that they may be placed directly on the microscope stage for examination, even with high magnification. If the microscope is equipped with a mechanical stage, the mounts may have two flat faces ground on their sides, so that they may be placed in constant position on the stage, and any point re-located by co-ordinate readings.

ABRASIVES.

The abrasives for the first three laps are sorted by Vanderwilt's method,[4] using No. 600 Alundum powder. By this method, the powder, suspended in water, is passed through a series of siphon jars in which the rate of flow is slower in each succeeding jar. Thus, in any given jar, particles over a certain diameter will settle out, while those smaller will be carried over to the next jar. With the jar sizes used by the writer, a flow of 80 drops per minute through the system yields in the second, third and fourth jars, grain diameters of .007–.008 mm., .004 mm., and .0025 mm., respectively. For the fourth lap, black magnetic rouge[5] has been found entirely satisfactory, while for the fifth lap, when a lead surface is used, levigated magnesia is best. Better results, however, are commonly obtained in this last stage, by using magnetic rouge on a cloth-covered lap.

POLISHING APPARATUS.[6]

A number of variations of the apparatus were tried; at first, two heads were used on opposite sides of one lap, but it was found that this arrangement caused the lap to wear too unevenly, grinding down the center more rapidly than the outside. Then one head was tried alone, and was found to work better, but the lap surface still became "cupped." Finally, the lap was cut down in diameter, and made with an annular surface, and the head that holds the specimens is, following Gillson, set slightly eccentric from the lap[7] (Figs. 2 and 6).

Motive power is supplied by a ¼ H.P. motor, with a speed of about 1200 r.p.m., which is reduced to about 165 for the head, and 100 for the lap. The head is mounted in a double vertical bearing, and held in place by thrust collars, so that none of its weight is borne by the specimens. It was designed to carry six

[4] Vanderwilt, J. W.: A laboratory method for grading abrasives. ECON. GEOL., vol. 24, pp. 853–859, 1929.

[5] This black magnetic rouge was obtained from Reynolds & Co., Los Angeles.

[6] A new polishing apparatus has recently been described by F. G. Phillips: Mineralogical Magazine, vol. 24, p. 595 (Sept. 1937).

[7] This principle has been developed by J. L. Gillson (personal communication).

specimens but only three or four of the holders are used, especially in the early stages of grinding. More than four specimens at once tend to produce an excess of abraded material that clogs the lap. The head is a disc, cast from red brass, with bosses on its

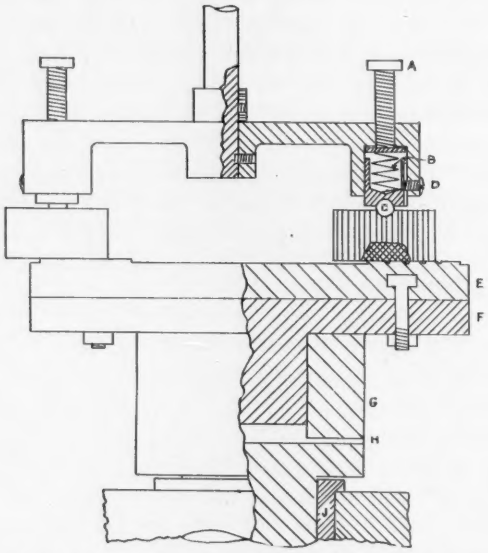

FIG. 6. Sectional view of head and lap, to show detail of construction. A = adjusting screw. B = coil spring. C = 5/16 in. ball bearing. D = stop screw to keep holder in place when no specimen is in position. E = lead casting, held in place by bolts. F = cast iron base. G = socket, with vent (H). J = upper bearing for head shaft.

under side, and is pinned solidly to the vertical shaft. The bosses are drilled out to receive the specimen holder proper (Fig 6). By means of the coil spring and the adjusting screw, a constant pressure of the specimen against the lap may be maintained. The writer uses a spring ⅞ in. long, made by winding No. 19 piano wire by hand on a ¼ in. arbor. With a mount of normal thickness, this spring, compressed about one-third of its length, will

produce a pressure of 2–3 lbs. Because of the ball-bearing connection, the point of application of the pressure will be the central point of the specimen, thus insuring equal pressure over the whole specimen surface. In addition, the specimen is free to rotate about this center in a horizontal plane, during the polishing process.

The lap shaft is operated by a V-belt running over two horizontal idlers, from a 20 to 1 reduction gear on the main shaft. It has a large vertical bearing at the upper end, machined accurately parallel to the head shaft, so that the head and lap rotate in exactly parallel planes. At the bottom, it has a ball thrust-bearing, to support the lap at a constant level. At the top end of the shaft, is a large cylindrical socket, machined to receive the stem of the lap. The laps, of which there are five, all have a cast iron base, accurately fitted to this socket. They will also fit a duplicate socket that can be set directly into the taper in the spindle of a precision lathe. Thus, by setting a lap in this socket, it can easily and rapidly be set in the lathe in exact position to be finished originally, or to be re-surfaced.

One lap is quarter-inch copper plate, fastened with brass screws to the iron base, which is blocked up to the proper thickness (1 1/32 in. from the back). The other laps are lead, cast directly on the base by clamping a metal strip around the edge, as a dam. The lead is held onto the base by three square-headed bolts, which can be tightened after the lead hardens (Fig. 6). The laps may be put in the lathe and accurately surfaced with no danger of having the lead slip out of position. The laps are all annular, with a finished diameter of 6¼ in. outside, and 3½ in. inside, with concentric grooving at ¼ in. intervals. The eccentricity of the head to the lap is such (7/16 in.) that the mounts successively overlap the outer and inner edges of the lap surface by approximately half an inch. Since the lap and head speeds are practically incommensurable, this insures a constantly changing path for each specimen over the lap surface, even wear on the lap, and hence even grinding of the specimen. The overlapping is necessary, since the average mineral fragment occupies only the central por-

tion of the mount surface, and is seldom much over ¾ in. across. It has been found that bakelite wears down the lap surface much less rapidly than does the specimen, so that unless the latter reaches the lap edge, a ridge will be developed there, due to differential wear. This ridge will produce a doming on the specimen surface, so that in later stages of polishing, only the central portion of the surface will be touched. The lap and head are geared to run in opposite directions, so that a nearly constant lap-to-head speed is maintained at all points.

To permit the changing of laps, the head assembly is fixed on a pivot, and can be swung aside on loosening the holding-down bolt. It is brought back to exact position by means of a tapered pin nting in a hole drilled into the base block.

A simplified modification of the Vanderwilt machine, using one copper lap and two lead, has been in use for some time at the Lake Shore Mine, in Canada.[8] This is quite inexpensive and has been found highly satisfactory for the polishing of ordinary specimens and minute particles of concentrates. The paper also describes a very ingenious method of microconcentrating and mounting these particles.

POLISHING.

The preparation of specimens for mounting and polishing is best accomplished by sawing a smooth surface with a diamond saw, as described by Graton,[9] but if such a saw is not available, a satisfactory surface may be produced on most specimens by an ordinary rotating grinding machine which may conveniently be used with a cloth covered lap for the last stage of polishing (see below). A chip of the specimen is first ground on a cast iron lap, using FFF carborundum. The specimen is then transferred to a lead lap, and ground with No. 101½ optical emery, which produces a very smooth, even surface, with the harder minerals, such as quartz and pyrite, even somewhat burnished. The softer

[8] The Staff: Milling investigations into the ore as occurring at the Lake Shore Mine. Can. Inst. Min. & Met. Tr., vol. 39, pp. 398–401, 1936.

[9] Graton, L. C.: Technique of mineralography at Harvard. Am. Mineral., vol. 22, p. 495, 1937.

minerals will have an evenly granular surface, and be free from pits or cracks. This operation does not seem to produce serious shattering of the brittle minerals, nor to lengthen unduly the time necessary for the complete polishing. In some instances it may be of vital importance to use all the refinements of treatment as described from the Harvard laboratories, but the lack of such facilities should not in general be a serious handicap; satisfactory results may be attained by using the initial procedure outlined above.

The mounted specimen is first ground on the copper lap, using .008 mm. abrasive, which is mixed to a thin paste with a mixture of three parts of kerosene to one part mineral oil. The abrasive is spread uniformly but sparingly over the lap surface before starting, and may be added by the finger tip from time to time, as needed during the grinding. The abraded material must not be allowed to accumulate on the lap, and may be removed by wiping the rotating lap with a kerosene-moistened cloth. If the lap is run too wet, the specimen will slide over the surface, without being abraded; if too dry, the abrasive and abraded material will "cake" on the lap surface, and cause trouble. The length of time required for this first stage varies with the proportion of hard minerals in the section, but should not exceed an hour; with a preponderance of soft sulphides, the time may perhaps be halved. On this lap the whole surface is made evenly smooth, and slightly "grained;" the pyrite loses any shine it may have received in the preparation. It has been found desirable to inspect the specimens every fifteen minutes during this grinding, wipe them off, and wipe the lap surface more thoroughly than is possible while the machine is running.

The specimens are then ready for the second lap (lead), with the same size abrasive. This gives a smoother surface, as the abrasive particles become embedded in the lap surface, and their effective cutting size is much reduced. About an hour on this lap, with inspection two or three times during the process, is sufficient for even the hard specimens, while softer ones will be finished in less time. The granularity of the surface is dimin-

ished in this stage, and some of the minerals may begin to show a really smooth finish, though not yet a polish.

The third stage is also on lead, but with .0025 mm. abrasive, the specimens, of course, being cleaned with the greatest care to avoid contamination of the lap by the coarser abrasive. Here the beginning of a real polish is developed on pyrite, and the soft minerals are smoothed still further, but still show a "grained" surface. One hour, with two inspections, is average time for this lap, but in some cases, particularly where there is fine grained pyrite, two or even more hours will be found necessary. Decreasing amounts of abrasive and of lubricant will be found necessary in the successive stages of grinding.

For the fourth stage, a lead lap is armed with black magnetic rouge, and the lap run with still lesser amounts of abrasive. Care must be taken not to run the lap too dry in this stage, otherwise the surface of the specimen will become "burned" and tarnished by the friction, so that the previous stage will have to be repeated. Inspection of specimens should be made every thirty minutes, and in most cases polishing will be complete in one hour. The hard minerals will now have a very perfect, mirrorlike polish, and the softer ones will be smooth, though somewhat scratched.

With this particular apparatus, the last lead lap, using levigated magnesia, has not proved very satisfactory. In general, the difficulty of avoiding scratches on the soft components at this point, renders it more advisable to finish the specimens in a different way. The writer has used a broadcloth-covered lap, as mentioned above, rotating at about 600 r.p.m., on which the specimens are lightly polished for a few moments, with rouge and water. This, when carefully done, produces a beautifully scratchless polish on the soft minerals, with a minimum development of relief between the hard and soft constituents of the section.

The temptation to speed up the grinding by the use of more abrasive, must be resisted, as throughout the whole grinding and polishing process there is a tendency for the development of relief between minerals of different hardness, due to the accumulation of debris from the grinding. This accumulation must be kept

at a minimum, by the use of small amounts of abrasive, and by keeping the laps properly wiped off.

The polished surfaces produced in this apparatus are, as shown in the accompanying microphotographs (Figs. 4 and 5), essentially mirror smooth, with very little relief developed between the hard and soft minerals. This sort of surface permits the use of high magnifications, and the observation of extremely minute relationships of minerals, a point often of the most vital importance in the study of ores. In view of this considerable advantage, over the results obtained by simpler methods of polishing, the time expended, and the more elaborate equipment required, are thoroughly justified.

UNIVERSITY OF CALIFORNIA AT LOS ANGELES,
April 22, 1938.

GEOLOGICAL OBSERVATIONS OF THE BLOCK P MINE, HUGHESVILLE, MONTANA.

KIRIL SPIROFF.

ABSTRACT.

Block P Mine, Hughesville, Montana, is located in a syenite porphyry plug—one of the many injections that have intruded the sediments of the Little Belt Mountains. Shear and tensional fractures are found within the mine. These fractures have been mineralized and were followed by dikes.

Hydrothermal mineralization has deposited mainly galena, sphalerite, and pyrite. Most of the silver is associated with copper-bearing minerals, tetrahedrite being the chief silver-bearing mineral.

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INTRODUCTION.

THE Block P Mine is located in the Barker mining district, in the Little Belt Mountains, sixty miles southeast of Great Falls, Montana (Fig. 1). It is composed of a group of claims of which the Barker and the Wright and Edwards properties are the best known. Intermittent production began about 1875 and continued until 1927, when these properties were taken over by the St. Joseph Lead Co. Extensive development was then started, and the mine was fully equipped. To date the total production of the Block P Mine is greater than the combined production of

all the other mines in the district, and in 1929 the Block P Mine was the largest lead producer in Montana.

The mine has been developed vertically to a depth of 1,400 feet and for a distance of 4,000 feet along the vein. Each level is

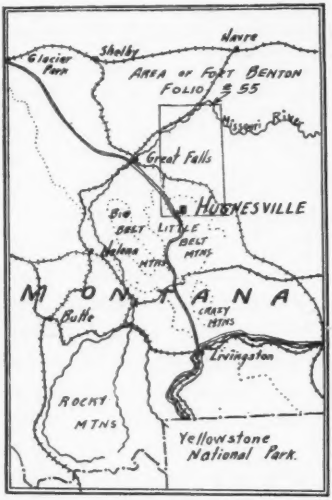


FIG. 1. Index map showing location of Block P Mine, Hughesville, Montana.

crescent-shaped in plan. The dip of the vein ranges up to twenty degrees from the vertical either way, and averages eighty degrees toward the center of the semicircle.

The ore is transported 10,250 feet by an aerial tramway to a 400-ton mill located on a bench of the old smelter site just below the town of Barker. Lead and zinc concentrates are produced. The mill is served by a privately owned railroad that joins the Neihart branch of the Great Northern Railroad at Monarch, Montana.

GENERAL GEOLOGY.

W. H. Weed [1] states that the Little Belt area is part of a broad mountainous uplift having the general structure of a wide arch

[1] Weed, W. H.: U. S. Geol. Surv. Rept. 20, pt. 3, p. 276.

with flat summit and steeply inclined sides much modified by local arches due to igneous injections, and that the stratified rocks constitute a section from the Cambrian to the Mesozoic. He also says:[2]

> The geology of the Barker district is more varied than that of any other area of equal extent in the Little Belt Range. The district is situated on the northern border of the Archean core of the range, where the uplift of the mountains has upturned the sedimentary rocks and tilted them northward. This normal tilting is, however, almost destroyed by the igneous intrusions of the district. These are of various rocks, and occur intrusive in various ways. Barker Mountain is a great mass that is laccolithic in character and has lifted up the sediments about it in a dome. Otter Mountain to the north is another laccolith which is as yet but partially revealed by erosion. Its sheets form Clendennin Mountain, whose slopes make the north wall of the Barker Basin. Mixes Baldy, the mountain to the east, and the peaks adjacent to it, are carved out of an intrusive mass punched through the strata—a great bysmalith. The center of the basin is occupied by a small stock of granular rock that may be the center of the igneous activity of the region.

The part of the Barker area discussed in the present report is that underlain by syenite porphyry, the small stock of granular rock mentioned in the foregoing quotation and explored in the Block P mine workings.

The syenite porphyry plug forms a low, pine-covered ridge. It is believed to be oval in shape and about a mile in diameter, an assumption based upon the drainage pattern. The contacts have not been definitely determined, however, except on the west side where the sugary limestone does not support vegetation. The syenite porphyry is cut by two known dikes, a quartz sanidine basalt porphyrite, which has a general northeast trend and dips 80° N., and a quartz porphyry dike with northwest trend and a probable dip of 80° NE.

PETROGRAPHY.

Syenite Porphyry.—Megascopically, a fresh specimen of the Hughesville syenite porphyry shows purplish gray phenocrysts of alkali feldspar in a gray phanerocrystalline groundmass having specks of biotite and a light green mineral. The microscope reveals idiomorphs of soda-orthoclase, microperthite, cryptoperthitic

[2] Idem, p. 346.

albite, and oligoclase in a groundmass of oligoclase, alkali feldspar, quartz, biotite and hornblende. There are few grains of magnetite and apatite. All the minerals in the rock show marked corrosion.

A chemical analysis of this rock is given in Table II. Although the content of silica is high, the field name of the rock, syenite porphyry, is retained, since the quartz grains are of microscopic size.

Basalt Porphyrite.—In the mine the basalt (quartz sanidine basalt porphyrite) dike varies in width from a few inches to twenty feet; in places it is sheared and crumbly, in others it is hard and rings from a hammer blow. The phenocrysts vary in character and distribution. One fresh sample shows glassy sanidine, quartz, and biotite in a gray groundmass. The microscope reveals idiomorphs of quartz, sanidine with oligoclase rims, diopside, and hypersthene. The groundmass contains microlitic andesine having a parallel arrangement that suggests flow around the phenocrysts. Other minerals in the groundmass are calcite, hematite, and kaolin.

Quartz Porphyry.—The quartz porphyry is found underground and in a number of shallow test pits along the ridge west of the Wright and Edwards shaft. The rock is light gray in color, with large glassy and smaller alkali feldspar phenocrysts and an equal number of quartz phenocrysts. The microscope reveals corroded idiomorphs of albite, oligoclase, and quartz showing partial resorption. There are also smaller idiomorphs of sericitized oligoclase and biotite, along with shreds of biotite, in a groundmass made up of microgranular intergrown quartz and feldspar, of numerous magnetite grains and of a few specks of apatite, pyrite, titanite, and secondary calcite.

The study of the thin sections of the fresh rocks from the mine did not reveal any outstanding mineral that can be used in correlation. A regional study is needed to determine the relationships between the dikes and the larger intrusive bodies.

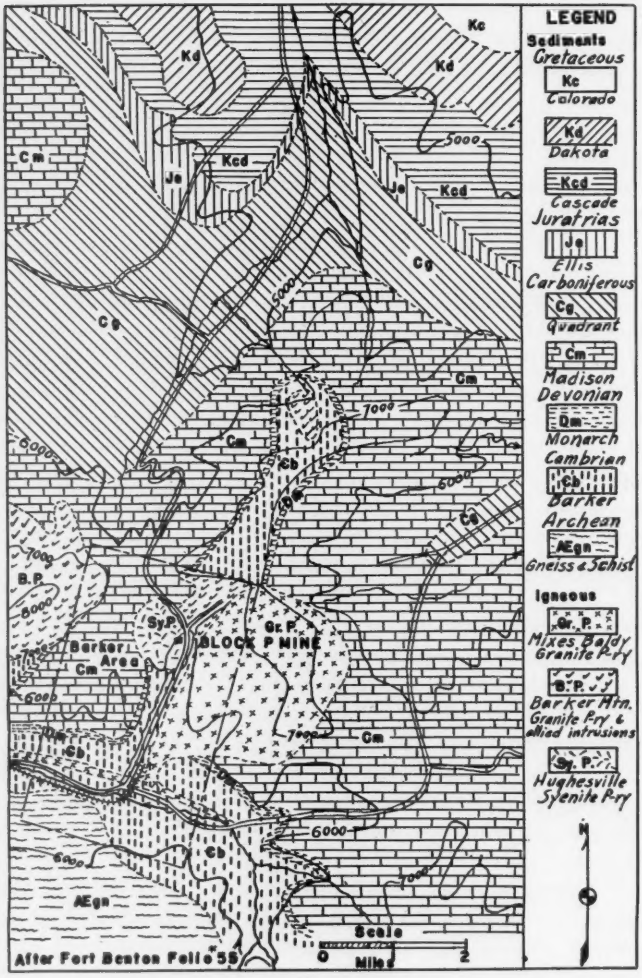


FIG. 2. Geology of Barker mining district, Hughesville, Montana.

STRUCTURE.

The general structure of the Barker area is shown in Fig 2. The Paleozoic formations have a regional dip to the north, but locally the dominant features are an anticline on the east side of the area and a syncline through the central part, both structures having axes that trend about N. 30° E. Several stocks of igneous rocks have been intruded into the sedimentary formations, of which one, an elongated plug of syenite porphyry, contains the Block P mine.

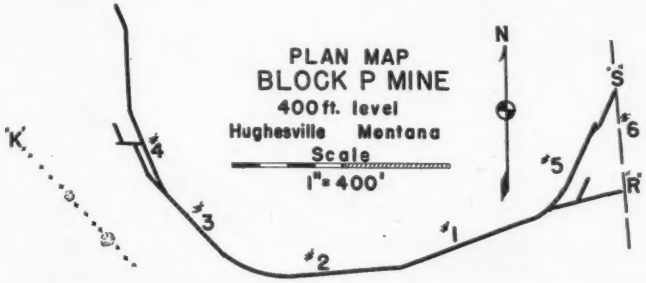


FIG. 3. Plan map of the 400-foot level, Block P Mine.

Within the mine the only structures are those due to fracture in the syenite porphyry and those due to mineralization or intrusions along the fractures. The main fractures are:

1. A vertical fracture of N. 60° E. strike that is mineralized and paralleled by the basalt dike.

2. A fracture that strikes N. 80° E. and dips about 80° N. also accompanied by the vein and basalt dike.

3. A fracture that strikes N. 50° W. and dips about 80° N. In the mine proper this is accompanied by the vein only. A quartz porphyry dike to the west approximately follows this fracture.

4. A vertical fracture of N. 20° W. strike accompanied by the vein.

5. A vertical fracture of N. 20° E. strike accompanied by the vein.

6. In addition to these fractures, there is probably a post-mineralization fault, striking N. 10° W. This assumption is based on the following facts. (1) The northeast end of the drift is in a talcy pyritized zone; and in the drift small displacements of the vein were observed. (2) The east-west offshoot drift ends fifty feet beyond the present workings, at point S.

Fractures No. 2, 1, 5, and 6 are considered to be shears and to have developed in the order given. Evidence of shearing along No. 1 and No. 2 is shown by the presence of closely spaced sheeting in the basalt dike and by small offsets in the basalt in the nature of overlaps.

The movement along fracture No. 5 is what is to be anticipated—that is, cutting off the basalt dike and displacing it.

FIG. 4. Intersection of shear and tension planes causing vein to curve.

The curved structure of the vein in the central parts is due to openings made possible by the joining of two planes. It has been observed elsewhere that where tension joints come close to shear planes they commonly curve as shown in Fig. 4.

The relationship suggested indicates a progressive change in the strain relation and fracture types of the same general order as are those formed experimentally, i.e., first the fracturing is dominantly tensional, and then gradually shears are produced, with the later movement mainly along the shear planes.

ORES.

Field observations and the study of polished specimens reveal that most of the ore is primary. Superficial alteration of the vein has produced a shallow zone of decomposed clayey limonitic material with small amounts of oxidized carbonate ores. The

oxidized zone extends to a depth of about thirty feet, below which the vein is composed of primary sulphides. At greater depth the structure of the vein remains the same and the tenor of the ore is unchanged. Aside from the pyrite, which is found disseminated through those portions of the syenite porphyry close to the fractures, the sulphides are confined to fissures in the syenite porphyry or at the contact with the dikes. The mineralization is from a few inches to four feet in width, and occurs as lenses that show rough banding—largely layers of galena, pyrite, and sphalerite. This banded structure has been broken up by later movement, and the openings have been filled with the same sulphides accompanied by barite, calcite, rhodochrosite, and quartz. Vugs are present and are the product of this final stage of mineralization. No comb quartz or symmetrical crustification has been observed.

The principal ore minerals are galena, sphalerite, pyrite, chalcopyrite, and tetrahedrite; of these the galena and the sphalerite are of economic importance. Silver and gold are present, silver predominating. In addition some cadmium and germanium have been reported, along with traces of cobalt, nickel, and antimony.

The gangue minerals are quartz, barite, calcite, rhodochrosite, and siderite. Table I shows the distribution of the metals as indicated by milling tests.

TABLE I.

	Silver oz.	Copper %	Lead %	Zinc %	Iron %
Heads	9.0	.03	6.0	5.0	——
Pb. Con.	50.0	1.4	56.5	4.4	10.0
Zn. Con.	26.4	.3	1.8	54.6	4.7
Tails	1.9	——	0.26	0.2	5.5

PARAGENESIS

A study of the polished specimens reveals that mineralization by both fissure-filling and replacement has occurred; however, it is difficult to estimate the relative importance of the two processes. The general paragenesis is shown in Fig. 5.

Pyrite appears in stringers and disseminated grains. In the vein the early pyrite, which was the first sulphide to form, is fractured, corroded, and replaced by the later sulphides. In the secondary quartz and carbonate-filled veinlets, the late pyrite appears as separate grains and in the vugs as a drusy coating on quartz crystals.

Galena is especially common in lenticular-shaped fragments, the texture of which is coarsely crystalline in the center and fine grained on the edges. The galena replaced pyrite and some of

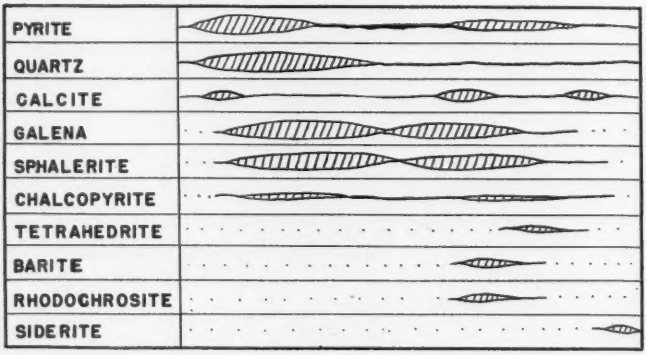


FIG. 5. General paragenesis of Block P Mine ores.

the basalt dike. Some of the galena cleavage plates are coated with crystalline chalcopyrite and calcite. The sequence of deposition of the galena and sphalerite is indefinite. In some specimens, apparently, the deposition of the two was simultaneous; in others the galena preceded the sphalerite, or *vice versa;* and in still others the one replaced the other.

The sphalerite occurs as veinlets in both pyrite and wall rock. It replaces the pyrite and has inclusions of chalcopyrite.

Chalcopyrite appears as blebs in the galena and sphalerite and as crystals in vug cleavage cracks. It definitely replaces all the sulphides with the exception of the tetrahedrite.

Tetrahedrite has been observed only in the pyrite, in which

it occurs as a coating or as a replacement of another sulphide at contacts or along cleavage cracks.

Of the gangue minerals, quartz is the most abundant. The early quartz is found in the rock wall, where it appeared along with the early pyrite in the metasomatic alteration; the late quartz is found as veinlets in all sulphides and as crystals in vugs.

Barite, calcite, and rhodochrosite appeared toward the end of the mineralization stage and acted as fillers or diluters, and because of their presence the sulphide mineral deposition became leaner. The barite, with its strong tendency to crystallize out in tabular plates, is prominent in crystalline forms around which carbonates and sulphides fill in the gaps.

Siderite and calcite have been observed on crystalline quartz in vugs accompanying small crystals of pyrite and a brownish black substance, probably a hydrated manganese iron sulphate.

THE SILVER DISTRIBUTION.

The 1929 production shows the silver distribution to be as follows:

9.09 oz. in the heads
50.19 oz. in the lead concentrates
30.86 oz. in the zinc concentrates
2.19 oz. in the tails

To determine which mineral carries the silver and whether the silver is uniformly distributed through the minerals, the ore was split up into various minerals by the use of gravity concentration (thallous formate and thallous malonate mixture), by flotation, and by hand sorting with the aid of the binocular microscope.

The polished specimens did not reveal any silver minerals.

The coarsely crystalline galena was first sorted out and screened, the galena that passed through 20 mesh and stayed on 40 being retained. Under the binocular microscope, clean shiny cleavage fragments were picked out; when assayed they gave 46.3 oz. of silver per ton—that is, less than 0.02 per cent. This galena was X-rayed, the powder method with sodium chloride as a standard being used. Only galena lines are shown by the diffraction patterns so obtained.

Impure galena assayed	44.3	oz. per ton
Impure sphalerite assayed	62.2	" " "
Pyrite with 5 per cent chalcopyrite	30.0	" " "
Pyrite with 5 per cent tetrahedrite	30.1	" " "
Pyrite with 1 per cent copper	14.1	" " "
Disseminated pyrite grains	Tr.	

A chalcopyrite concentrate yielded by flotation assayed 520 ounces of silver per ton, the highest silver concentration obtained by the writer. No briquets of the above concentrates were made to see whether any silver mineral was present. At the mill, no copper concentrate is made, but the copper sulphides are floated with the galena, and therefore the galena concentrates assay higher in silver than they would otherwise. Assays made on various tarnished and corroded pyrite specimens having various amounts of copper showed that the silver content increases with the copper content. The silver in the galena seems to be of uniform content, whereas that of the sphalerite is very erratic. This is to be expected, since a study of the polished specimens reveals sphalerite minutely intergrown with other sulphides and since the obtaining of pure sphalerite is difficult.

From the tests the following general conclusions may be drawn: The silver is associated with the four sulphides—galena, sphalerite, chalcopyrite, and tetrahedrite. Of these, the copper sulphides carry the greatest amount; the pyrite carries no silver; the loss of silver in the tails can be traced to the tetrahedrite, which, since it does not completely coat the pyrite, is depressed with pyrite in flotation.

WALL ROCK ALTERATION.

The partly altered syenite porphyry near the vein contains disseminated pyrite and fractures filled with pyrite. Also, it is paler in color than the fresh specimen, the alkali feldspar phenocrysts being dull and quite soft. Under the microscope may be seen corroded phenocrysts of soda-orthoclase and microperthite with blebs of sericite, quartz, and included sericitized and silicified feldspar. The groundmass consists of interstitial quartz, of

magnetite, and bleached ferro-magnesian minerals partly replaced by hematite, carbonates, and pyrite. A small amount of unaltered apatite is also present.

The highly altered syenite porphyry immediately adjacent to the vein is altered into a whitish gray rock in which the alkali feldspar phenocrysts have a pearly luster. A specimen crumbles easily and on the dumps disintegrates rapidly into fine dust. The microscope reveals corroded phenocrysts of soda-orthoclase with blebs of sericite, quartz, and calcite in a groundmass of quartz, sericite, pyrite, and shredded ferro-magnesian minerals partly replaced by calcite and sericite. The rock contains a larger amount of quartz than the less altered phase. Some of the quartz has rutile inclusions.

The altered specimens of the basalt dike crumble and disintegrate on handling. They show crystals of sanidine, quartz, and biotite in a greenish-gray mud-like groundmass. The microscope reveals sericitized feldspars, interstitial quartz, calcite, hematite, and a brown semi-opaque mineral.

The altered quartz porphyry is a light gray rock from which quartz grains can be picked out. The microscope reveals corroded idiomorphs of sericitized feldspar and quartz (some having rutile needles) in a groundmass of pyrite, calcite, muscovite and unrecognizable brown semi-opaque material.

In summary, the wall rock shows the following, all of which are characteristic of hydrothermal alteration: leaching of the lime-bearing feldspars, sericitization, and silicification of small grained feldspars, complete alteration and leaching of the ferro-magnesian minerals, change of magnetite to hematite and carbonates, increase in quartz, and the appearance of pyrite and calcite.

ROCK ANALYSES.

In making the following chemical analyses (Table II) the writer's purpose was to determine whether or not there is any outstanding difference in composition that might be used to distinguish one magma from another. As the results show, no such

TABLE II.

Rock	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	Sp. Gr.
Fresh syenite porphyry	65.35	4.25	15.85	2.40	1.30	2.61
Alt. syenite porphyry	66.25	2.96	16.20	1.80	0.25	2.54
Basalt dike	56.90	6.60	15.80	3.40	2.36	2.74
Barker granite	67.30	4.00	15.90	1.60	0.70	2.60
Mixed Baldy granite	69.30	3.66	13.60	1.50	0.50	2.55
Clendennin Mount	66.85	3.73	12.30	1.00	1.60	2.51

[3] Total iron.

distinguishing features were found, with the exception of the basalt dike, which is more basic. Rock analyses were made by the writer at the Anaconda Reduction Works, Anaconda, Montana.

CONCLUSION.

The secondary structures of the Block P Mine consist of joints and faults that form a pattern which indicates that they were developed during the folding of the region. The presence of dikes and mineralization along the fractures in the mine, and the laccolithic structure of several of the larger intrusive masses in the area, show that deformation, intrusion, and mineralization are related processes in this area.

The ore minerals are galena, sphalerite, chalcopyrite, and tetrahedrite, which have been deposited along the fractures by filling and replacement. The ore is practically all primary, supergene alteration being present only in the upper few feet of the vein. From the character of the mineralization, the wall rock alteration, and the time relation to the intrusive processes, it is concluded that the veins were formed by hydrothermal solutions.

Analyses of pure crystals of the various sulphides in the ore and comparison of the assay values with various types of concentrates of ore show that most of the silver is carried by the copper sulphides.

ACKNOWLEDGMENT.

The writer wishes to thank Dr. C. O. Swanson, of the University of British Columbia, Vancouver, Canada, Dr. J. L. Adler, President of the Independent Prospecting Company, Houston, Texas, and Dr. Ella L. Wood, of the Language Department of the Michigan College of Mining and Technology for their help in the preparation of this manuscript.

MICHIGAN COLLEGE OF MINING AND TECHNOLOGY,
HOUGHTON, MICH.,
April 4, 1938.

DISCUSSION AND COMMUNICATIONS

THE PARAGENESIS OF PYRRHOTITE.

Sir.—In a recent discussion of "The Paragenesis of Pyrrhotite," [1] Roland Blanchard gives a description of the occurrence of pyrrhotite at Mt. Isa which is most interesting and timely. Unfortunately, this data, as well as that given by Grondiis and Schouten, was not available at the time the original paper was prepared. Blanchard's description seems to show that pyrrhotite does occur in abundance in at least one moderate temperature deposit. One wishes there were more explicit statements of occurrences such as Mr. Blanchard's. It was not the writer's intention to limit pyrrhotite strictly to a high temperature as is indicated by the word "mainly" in the third line quoted by Mr. Blanchard. The extensive review of the literature, however, still warrants the generalization which has been made by many writers, but some modification is in order.

On other points, however, Mr. Blanchard definitely misinterprets the writer's statements. Various points will be considered in order and stated as briefly as possible.

On page 220, second paragraph, Mr. Blanchard states that the writer substantiates his contention that pyrrhotite is a high temperature mineral by citing its occurrence with pentlandite. Reference to the original paper will show that no contention was made in the paragraph and there is no arguing in a circle because there is no argument in the section on pentlandite. It is simply a statement of fact derived from descriptions by several writers. Mr. Blanchard might well beware of such phrases as "stretch of imagination," "distortion of facts," "judicial attitude," used in regard to another's work when he misinterprets simple statements of fact.

[1] ECON. GEOL., vol. 33, pp. 218-225, 1938.

A similar misinterpretation is repeated on page 223 where he says, "attention might be directed to the 'evidence' that chalcopyrite is a high temperature mineral." The writer made no statement that chalcopyrite is a high temperature mineral but simply pointed out the fact that it is the principal copper mineral in all of the high temperature deposits. Chalcopyrite occurs throughout the range of copper deposits as every student of ore deposits knows, but in lower temperature deposits several other copper minerals are also abundant. Mr. Blanchard goes on to say, "The fact that both pyrrhotite and chalcopyrite are associated in numerous high temperature deposits in no sense establishes them or their association as irrefutable evidence of high temperature deposition." Since this occurs just below a quotation from the writer's paper, it is presumably directed at him, but there is no statement to that effect in the paper referred to. In geological work it would be extremely unwise to claim that anything was irrefutably established. Our knowledge of the complex facts involved is much too limited.

The writer's statements regarding bornite are also questioned. The Merwin-Lombard diagram was published after the writer's paper and even this or Mr. Blanchard's explanation does not explain why in supergene ores several investigators have noted the absence of bornite with pyrrhotite whereas chalcocite should be even more incompatible according to the indicated relationships. Here, too, the problem is not as simple as it may seem at first glance.

Some of the suggestions as to careful reasoning should certainly be applied to the statement about volcanic gases on page 224. The relative amount of constituents is most assuredly not always the primary determining factor in precipitation. Some minerals, for example, cannot be deposited at certain temperatures no matter what the concentration, but other minerals containing the same elements may be stable. Concentration, temperature, and pressure are the common variables that determine the state of a system, and no one of them can be said to be the determining factor, except in specific cases where all the factors are known.

The writer is willing to reiterate that there are puzzling facts in the association of pyrite and pyrrhotite.

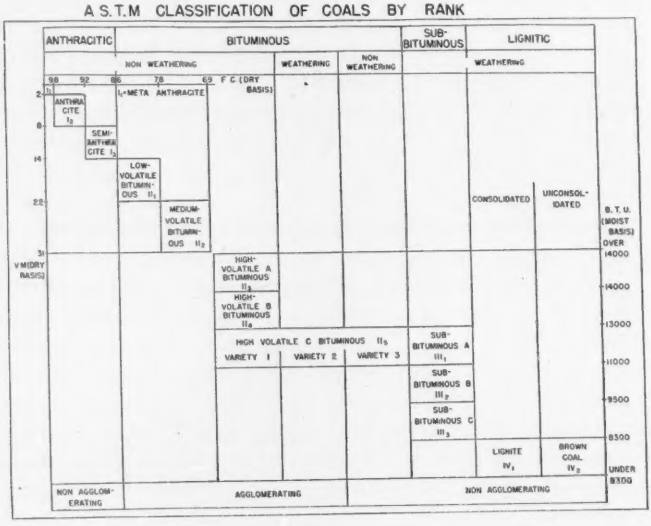
Regarding the occurrence of pyrrhotite in, and its indication of, high temperature deposits, it is probable that the writer was too emphatic. It would be very much worthwhile if other workers could add to Mr. Blanchard's example of abundant pyrrhotite in a deposit of a probable moderate temperature type.

G. M. SCHWARTZ.

UNIVERSITY OF MINNESOTA,
MINNEAPOLIS, MINN.,
April 11, 1938.

CLASSIFICATION OF COALS.

Sir: The paper of Thomas A. Hendricks on "Recently Adopted Standards of Classification of Coals by Rank and by Grade," published in the March-April issue of Economic Geology, is a fine exposition of these very important coal classifications. However,



the arrangement of Table I can be altered to permit easier understanding of the limits of Fixed Carbon and B.t.u. and of the requisite physical properties for each group. The accompanying Fig. is one such rearrangement and the response of students to this arrangement has convinced me that it is much easier to understand than the usual tabular presentation.

B. C. FREEMAN.

REVIEWS

Economic Geology. By H. Ries. 7th edition. 720 pp. John Wiley & Sons, Inc. 1937.

Although a number of changes have been made in the subject matter, the plan of this new edition remains the same as in the last one. The chapter on petroleum and gas has been completely revised. The book contains a large amount of information and a valuable bibliography.

The many editions testify to the regard in which it is held by numerous teachers.

The framework of the book is economic—chapter headings are mineral products—, which results in little geological correlation or continuity. The reviewer believes this to be a serious defect in a book which might be used as a textbook in studying the geology of mineral deposits. On the other hand, this arrangement contributes to making it an excellent reference book on mineral products.

W. H. Newhouse.

Mass. Inst. of Technology,
Cambridge, Mass.

Scientific Illustration. By J. L. Ridgway. Pp. xii + 173; pl. 22; figs. 23. Stanford University Press, Stanford University, Cal., 1938. Cloth 7 × 10. Price, $4.00.

The preface of Mr. Ridgway's book states that it "is primarily intended to aid students of science and others engaged in the preparation of manuscripts that require illustrations," but "is not a manual of free hand drawing—its matter relates to more advanced preparation, including well recognized and effective methods of procedure in producing finished illustrations."

The book gives directions for the preparation, assembling and display, and the production of illustrations for scientific publications. It goes without saying, that, with Ridgway as its author, the volume is full of good suggestions to those responsible for such illustrations, and good advice for those preparing them. Directions for making the various kinds of copy for different types of illustrations are not given in detail, but the methods that have proven most successful in the preparation of copy most suitable for different processes of reproduction are outlined, and

many suggestions are made as to the proper manipulation of the material employed in preparing satisfactory copy. Special attention is devoted to the drawing of maps, structure sections, and block diagrams and a brief account of the processes employed in reproducing illustrations is given.

There is an appendix of 17 tables listing data of importance to draughtsmen, especially to those interested in map-drawing, and an index.

The volume is beautifully illustrated with helpful plates and figures. It is worthy of the author's reputation as a leader in the preparation of scientific illustrations.

W. S. BAYLEY.

Journal of Geomorphology, Vol. 1, No. 1, Feb., 1938. DOUGLAS JOHNSON, Editor. Columbia University Press, New York. Price $4.00 a year.

We welcome this new venture in its new field. The first number of 88 pages contains a Salutatory by the editors and papers by C. K. Wentworth, E. de Martonne, S. W. Wooldridge and D. L. Linton, and by S. B. Jones. It carries an editorial, and contains departments on "Studies in Scientific Method" and "Geomorphic Notes on Maps" with communications in them by Douglas Johnson and H. S. Sharp. It also carries a review department with 8 reviews, an abstract department with 9 abstracts, and a department of "Current Notes on Geomorphology."

The journal has made a brave start and should fill a need in the field of geomorphology.

ALAN BATEMAN.

A Descriptive Petrography of the Igneous Rocks. Vol. IV. Part I, Feldspathoid Rocks; Part II, Peridotites and Perknites. By ALBERT JOHANNSEN. Pp. 523; figs. 180. Univ. of Chicago Press, 1938. Price $4.50.

This fourth volume, following quickly after the third, treats of these two groups of rocks in the same manner as the two preceding volumes. Rock families 13 to 25, the feldspathoid rocks, are taken up, and in Part II, the peridotites and perknites of families 0 to 12. The volume shows the same careful work as its predecessors, and has, as before, many photo inserts of geologists whose names are associated with these rocks.

Landslides and Related Phenomena. By C. F. SHARPE. Pp. 137; figs. 16; pl. 9. Columbia University Press. New York, 1938. Price $3.00.

This volume is No. 2 of the Columbia Geomorphic Studies edited by Douglas Johnson. It reviews our knowledge of mass-movements, which

includes landslides and related flow types. It considers the underlying causes and the relation to denudation and soil conservation. The movements are classified and are discussed under Slow Flowage, Rapid Flowage, Landslide, and Subsidence. The relations of the various types to climatic and geomorphic cycles are pointed out, and the slow movements such as mud flow and debris flow are emphasized.

This volume should prove of interest not only to geologists and to geographers, but also to those interested in engineering, soils, and soil conservation.

The Gold Missus. By KATHARINE FOWLER-LUNN. Pp. 303. W. W. Norton, New York, 1938. Price $3.00.

Geological and geographical reminiscences of an American woman geologist who married an English geologist from Rhodesia. When he was sent to the Gold Coast, she geologized little known Sierra Leone by herself, where she was nicknamed "the Gold Missus." She tells of her experiences and geological findings as she trekked the jungle in the search for chromium and gold, and in mapping molybdenum. It is an interesting novel but contains also geological observations of interest and value.

BOOKS RECEIVED.

J. D. BATEMAN.

The Valdez Creek Mining District, Alaska, 1936. R. TUCK. Pp. 20; figs. 4. U. S. Geol. Surv., Bull. 897-B, 1938. Price, 5 cts. *Placer and lode gold.*

The Mineral Industry of Alaska in 1936. P. S. SMITH. Pp. 107; figs. 4; map. U. S. Geol. Surv., Bull. 897-A, 1938. Price, 30 cts. *Gold, silver, copper, lead, platinum metals, tin, coal, and petroleum.*

Mines and Mineral Resources of Newfoundland. A. K. SNELGROVE. Pp. 162; figs. 22; pls. 16; maps, 6. Nfld. Geol. Surv., Information Circ. 4, St. John's, 1938.

Report on the Groete Creek and Mariwa Goldfields of the Lower Essequibo and Lower Cuyuni Rivers. D. A. BRYN DAVIES. Pp. 17. **Occurrence of Manganese Ore at Suxacalli, Lower Essequibo River.** D. W. BISHOPP. Pp. 4. Brit. Guiana Geol. Surv., Bull. 6, 1936. Georgetown, 1938. Price, 24 cts.

Upper York River Map-Area, Gaspé Peninsula. W. I. JONES. **Marbleton and Vicinity, Dudswell Township, Wolfe County.** ABBÉ J. J. W. LAVERDIÈRE. Pp. 42; pls. 5; maps, 2. Que Bur. Mines, Ann. Rept., 1935, Part D. Quebec City, 1936. *Areal geology.*

Phosphate-Rock. G. I. WHITLATCH. Tenn. Div. of Geol., Markets Circ. 8. Nashville, 1938.

Geology of Rawlins and Decatur Counties with Special Reference to Water Resources. M. K. ELIAS. Pp. 25; figs. 2; maps, 2. Kan. Geol. Surv., Min. Res. Circ. 7, 1937.

Stages and Flood Discharges of the Connecticut River at Hartford, Connecticut. H. B. KINNISON, L. F. CONOVER, AND B. L. BIGWOOD. Pp. 18; figs. 2; pl. U. S. Geol. Surv., W-S Paper 836-A, 1938. Price, 10 cts. *Statistical.*

Les Phénomènes de Polarisation Spontanée Électrique du Sous-Sol. E. POLDINI. Pp. 42; figs. 17. Mém. de la Soc. Vaudoise des Sci. Nat. Lausanne, 1938. Price, 2 fr. *Electrical polarization of subsoil attributed to combination of cosmic and local causes.*

Laboratoriumsbuch für Gaswerke und Gasbetriebe aller Art. Part I. F. SCHUSTER. Pp. 168; figs. 80; pls. 9. Wilhelm Knapp, Halle (Saale), 1937. *A manual of technique for investigation of solid and fluid materials.*

Decolorization of Southern Illinois Silica. J. S. MACHIN AND F. V. TOOLEY. Pp. 35; figs. 14. Ill. Geol. Surv., Rept. of Investigations 47. Urbana, 1937.

Rock Wool Resources of Kansas (Appendix). N. PLUMMER. Pp. 28; figs. 13. Kan. Geol. Surv., Min. Res. Circ. 8, 1937.

Micro-Paläontologische Untersuchungen zur Stratigraphie des nordwest deutschen Lias und Doggers. HELMUT BARTENSTEIN AND ERICH BRAND. Pp. 224; figs. 20; pls. 20. Abh. Senckenberg. Naturf. Ges., 439. Frankfurt a. M., 1937. *Many descriptions of species; excellent plates.*

Die Geologie der Prümer Mulde. LUDWIG HAPPEL AND HANS T. REULING. Pp. 94; figs. 17; pls. 10; maps, 5. Abh. Senckenberg. Naturf. Ges., 438. Frankfurt a.M., 1937. *Structure and geomorphology.*

Manganese Resources of the Tennessee Valley Region. H. S. RANKIN, R. A. LAURENCE, AND F. A. W. DAVIS. Pp. 30; pl. T. V. A., Geol. Div., Bull. 7. Knoxville, 1938.

Preliminary Statement on the Mineral Production of the Province of Quebec, 1937. Pp. 11. Bur. Mines, Quebec City, 1938.

Eagle-McDame Area, Cassiar District, British Columbia. G. HANSON AND D. A. MCNAUGHTON. Pp. 16; map. Can. Geol. Surv., Mem. 194, 1936. Price, 10 cts. *Placer and lode gold.*

Little Southwest Miramichi-Sevogle Rivers Area, New Brunswick. E. W. SHAW. Pp. 13; pls. 2; map. Can. Geol. Surv., Mem. 197, 1937. Price, 10 cts. *Pre-Silurian to Pennsylvanian.*

Geology of the Woodstock Area, Carleton and York Counties, New Brunswick. J. F. CALEY. Pp. 21; pl.; map. Can. Geol. Surv., Mem. 198, 1936. Price, 10 cts. *Silurian sedimentary iron deposits.*

Mining Industry of Yukon, 1936. H. S. BOSTOCK. Pp. 13; pl. Can. Geol. Surv., Mem. 209, 1937. Price, 10 cts.

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A Microscopical Study of the Bawdwin Ores, Burma. J. A. DUNN. Pp. 37; pls. 8. Rec. Geol. Surv. India, pt. 3, 1937. *Includes data on etch tests and optical properties of a few opaque minerals.*

The Laws of Rock Metamorphism. V. M. GOLDSCHMIDT (trans. by T. T. Quirke). Pp. 28. Univ. Ill. Supply Store, Champaign, 1937. Price, 65 cts. *Literal translations of two of V. M. Goldschmidt's classic papers on metamorphism.*

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Quicksilver in Oregon. C. N. SCHUETTE. Pp. 172; figs. 27; pls. 46. Oregon Dept. Geol. and Min. Indust., Bull. 4. Portland, 1938. Price, $1.15. *Occurrence of cinnabar deposits; mining and metallurgy.*

Geology and Natural Resources of West Virginia. P. H. PRICE, R. C. TUCKER, AND O. L. HAUGHT. Pp. 462; figs. 61; pls. 231; map. West Va. Geol. Surv., vol. 10, 1938. *Reference book on resources of West Va., as well as text for State University.*

Mother Earth. G. W. ROBINSON. Pp. 202. Thos. Murby & Co., London, 1937. Price, 5/6. *Series of essays in form of letters to Prof. R. G. Stapledon on soils, humus, fertility, fertilizers, surveys, and waste lands. Light reading.*

An Introduction to Geology. A. E. TRUEMAN. Pp. x + 245; illus. 133. Thos. Murby & Co., London, 1938. Price, 4 s. *An elementary geology for schools. Emphasizes observations in the field. Simple and clear. Covers a wide field.*

Outline of the Principles of Geology. Revised by R. M. FIELD. Pp. 209; figs. 122. Baines & Noble, New York, 1938. Price, $1.00. *A very condensed review of a course in geology, e.g. economic geology in 12 pages; previous errors mostly eliminated.*

Dynamik der Deutschen Acker—und Waldböden. W. LAATSCH. Pp. xii + 270; pl. 4; figs. 56. Th. Steinkopff, Dresden, 1938. Price, paper 20 Rm. *Origin and development of soils; thesis that soils are individual dynamic systems whose reactions are dependent upon climate and structures.*

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SCIENTIFIC NOTES AND NEWS

PAUL H. PRICE, State Geologist and Associate Professor of West Virginia University, has been made professor and head of the Department of Geology and will continue to serve as state geologist.

MACK C. LAKE, consulting geologist and mining engineer, has announced removal of his office to 400 Call Building, 74 New Montgomery St., San Francisco.

PHILIP F. FIX of Boulder, Colorado is with the National Park Service for the summer in Yellowstone National Park.

PERCY E. BARBOUR, consulting mining engineer, spent March and April on a professional trip to Colombia.

DAVID GALLAGHER has recently returned from the Lupa goldfield, East Africa.

WARREN M. WOODWARD, who has been geologist at the Mountain Con mine of Anaconda Copper Co., is now with the exploration department of Fairbanks Exploration Co. in Fairbanks, Alaska.

JOHN C. REED, GERALD FITZGERALD, F. H. MOFFITT, T. W. RANTA, J. B. MERTIE, JR. and PHILLIP S. SMITH, from the Washington office of the U. S. G. S., are conducting geological examinations and investigating developed properties in Alaska this summer.

ROYAL P. JARVIS, geologist and mining engineer for Mineral de Dos Estrellas, Michoacan, Mexico, has left for El Oro, Mexico.

E. F. REED, chief engineer and geologist of the Andes Copper Mining Co. at Potrerillos, Chile, spent May and June on vacation in Hollywood, California.

EDWARD WISSER who has been with Consolidated Mines Inc. in the Philippines is now engaged in general consulting work with address at 1986 Yosemite Road, Berkeley, California.

W. B. MILLAR is back in New York after sixteen months exploration in Eritrea and Abyssinia.

J. HARLAN JOHNSON, associate professor of geology at the Colorado School of Mines, is spending the summer in Europe.

C. H. BEHRE, JR., has returned to Northwestern University after a year's leave of absence spent in studying the origin of lead and zinc deposits in Europe and northern Africa under a Guggenheim Fellowship.

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